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NOTES ON THE GEOLOGICAL SECTION OF MICHIGAN[1]

PART II. FROM THE ST. PETER SANDSTONE UP

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INTRODUCTION

An apology is due for the long gap which has elapsed between the publication of Part I and Part II. This is due to the fact that I wished to have the benefit of the work of Professors A. W. Grabau and W. H. Sherzer without trespassing upon their rights. This I can now do[2] though we are not yet in accord as to interpretation. Perfect accord, however, cannot be expected. An advantage is that in the mean time Schuchert's[3] and other paleogeographic studies have appeared. This paper was written before Schuchert's and independently, so that the numerous confirmations of his maps are valuable checks, while discrepancies have not been subject to critical revision. Almost all the places referred to will be found underlined on a map in Vol. V of the *Mich. Geol. Survey*, and detailed references to the facts upon which the statements of this paper are based will be found in the report for 1908.

The second, or upper part of the Michigan rocks here described, including Ordovician and Carboniferous, has peculiar interest in many ways. In the first place it stands as the connecting field between the standard New York and the Mississippi Valley rocks.

[1] Part I appeared in XV, 680, of this *Journal*.

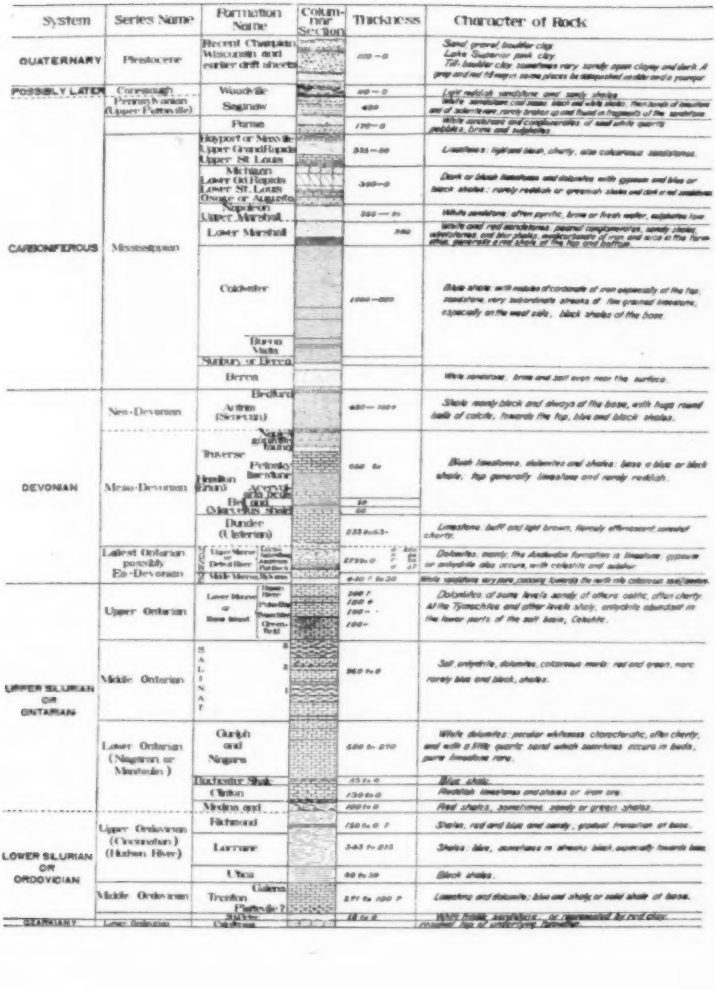
[2] See Grabau's papers in *Science*, No. 739 (1909), 356; *Bull. G.S.A.*, XVII, 567–636; XIX, 540–53.

[3] *Bull. G.S.A.*, XX (1910), 427–606.

In the second place it has not been much disturbed. It is too much to say not at all disturbed, for there is caught in the synclinal fold of Limestone Mountain on Keweenaw Point the Niagaran, so that we are led to infer that notable disturbance took place along the line of the Great Keweenaw fault after the Niagara. There are in the Lower Peninsula also signs of slight foldings at various times. But on the whole the strata lie in one vast little-disturbed *persistent* basin, Schuchert's Ontario Traverse Basin, in a gentle embayment of the great pre-Cambrian boss or shield which curves around them from Wisconsin on the west to Canada on the east. It is possible that at the center of this basin Paleozoic deposition was continuous, perhaps not always marine.

A notable feature is the general fineness of the sediments and absence of conglomerates. These latter are extremely rare. If one overlooks some perhaps autoclastic limestone calcirudites, occasional pebbles of quartz as big as peanuts and in the Marshall a few narrow thin bands of conglomerate containing very little but quartz, he may say there are none. The wide variety of crystalline and igneous rocks which lie only a short distance northeast to northwest are practically absent until, of course, we come to the glacial till, where they are abundant. These facts seem strong grounds for believing that during all the Paleozoic time this great area was neither glaciated nor violently disturbed and uplifted. We ought to have therefore in the Michigan section an ideal place, where the strata are well exposed, to study those universal advances and retreats of the shore-line which must have occurred as the ocean level was raised the world over by filling-in of sediments, or lowered by falling-in of blocks of the ocean floor. It is likely that we can recognize already the broad outlines of Huntington's steady and more unsteady periods as follows:

Relatively Steady	Relatively Unsteady
Jurassic and Cretaceous	Tertiary and Quaternary
Upper Mississippian	Permo-Carboniferous and Triassic (New Red)
Middle Devonian	Upper Devonian (Old Red)
Niagaran	Lower Devonian and Late Silurian
Trenton-Utica	Upper Ordovician Lorraine to Clinton
(Ozarkian ?) Calciferous ?	St. Peter sandstone minor
	Early Cambrian and Keweenawan
Animikie black slate	Palms and Goodrich
Kona dolomite and Grenville limestone	Possibly an oscillation below Keewatin


System
Series Name
Formation Name
Columnar Section
Thickness
Character of Rock
QUATERNARY
Pleistocene
Recent, Champlain, Wisconsin, and earlier drift sheets
100 — 0
Sand, gravel, boulder clay
Lake Superior peat, clay
Till, boulder clay, sometimes very sandy, open clayey and dark, A gray and red till may in some places be distinguished as older and younger
POSSIBLY LATER
Cretaceous
Woodville
80 — 0
Light reddish sandstone and sandy shales
Pennsylvanian (Upper Pottsville)
Saginaw
450
Mainly sandstone, coal seams, black and white shales. Thin beds of limestone and of siderite nodules, rarely bright opal and fluorite in fragments of the sandstone
Parma
170 — 0
White sandstone and conglomerates of vein white quartz pebbles, brown and subfeldspathic
CARBONIFEROUS
Mississippian
Bayport or Napoleon
Upper Grand Rapids
Upper St. Louis
335 — 50
Limestone; light and black, cherty, also calcareous sandstones.
Michigan
Lower Grand Rapids
Lower St. Louis
Osage or Augusta
300 — 0
Dark or black limestones and dolomites with gypsum and blue or black shales; rarely reddish or greenish shales and dark or red sandstones
Napoleon
Upper Marshall
200 — 0
White sandstone, often pyritic, brown or fresh water, subfeldspathic base
Lower Marshall
240
White and red sandstones, pebbly conglomerates, sandy shales, siderite band, and blue shales, erythrochroite of iron and mica in the form of the, greenish & red shale, of the top and bottom
Coldwater
1000 — 600
Blue shale with nodules of carbonate of iron especially at the top, sandstone, very subordinate streaks of fine grained limestone, especially on the west side, black shales at the base
Devonian
Antrim
Sunbury, or Berea
Berea
White sandstone, brown and soft even near the surface.
DEVONIAN
Neo-Devonian
Bedford
Antrim (Sherwin)
400 — 100+
Shale, mostly black and always at the base, with huge round balls of calcite, towards the top, blue and black shales.
Meso-Devonian
Traverse
Dundee (Ostrum)
Lucas
Alpena
Potosky Limestone
Alpena Limestone
Bell and Genesee Shale
600 to
Blue limestones, dolomites and shales, base a blue or black shale, top generally limestone and rarely reddish.
Dundee (Ostrum)
Limestone, buff and light brown, flaxsely effervescent, somewhat cherty.
Lateral Ontarian possibly Eo-Devonian
Upper Silurian or Detroit River
Middle Silurian
Sylvania
Bois Blanc
Amherstburg
Put-in-Bay
Lockport
Guelph
Niagara
Dolomites, mostly the Amherstburg formation a limestone, gypsum or anhydrite also occurs, with celestite and sulphur.
UPPER SILURIAN OR ONTARIAN
Upper Ontarian
Lower Marshall or Bois Blanc
Sylvania
Detroit River
Amherstburg
Put-in-Bay
Lockport
Guelph
Niagara
Dolomites of some levels sandy of others oolitic, often cherty. All the Tymochtee and other levels shaly, anhydrite abundant in the lower parts of the salt base, Celestite.
Middle Ontarian
Salt, anhydrite, dolomites, calcareous marls red and green, more rarely blue and black, shales.
Lower Ontarian (Niagaran or Manitoulin)
Guelph and Niagara
Dolomites, peculiar whitewash characteristic, often cherty, and with a little quartz sand which sometimes occurs in beds, pure limestone rare.
Dolomite Shale
Clinton
Medina and
Blue shale.
Reddish limestones and shales or iron ore.
Red shales, sometimes sandy or green shales.
LOWER SILURIAN OR ORDOVICIAN
Upper Ordovician (Cincinnatian) (Hudson River)
Richmond
Lorraine
Utica
Shales, red and blue and sandy, gradual transition at base.
Shales, blue, sometimes in streaks black, especially towards base.
Black shales.
Middle Ordovician
Galena
Trenton
Platteville?
Limestone and dolomite, blue and shaly, or solid shale at base.
CAMBRIAN
Lower Ordovician
Shakes
Oneidian
White friable sandstone, or impregnated by red clay, occasional flags of white grey sandstone

ORDOVICIAN

11. *St. Peter sandstone.*—There is no probability that these periods are of uniform length or intensity of oscillation. The unsteady period between the Trenton and Calciferous (Canadic-Ordovicic) appears to be much less important than the great period terminating in the Lake Superior overlap which in Michigan at least may include a good part of Ulrich's Ozarkian,[1] and perhaps earlier (the Keweenawan) during which Michigan was out of water and rent by tremendous volcanic outbursts.

In an emergence sandstone the sand itself, being rehandled along a rising coast, is more likely to be uniform in texture. Its connate water may be fresh at the margin. In many respects the St. Peter sandstone is a typical emergence sandstone as compared with the Lake Superior sandstone and that is one reason why I do not think it extends into the Lake Superior basin. As Schuchert's curve[2] indicates it does not mark so much emergence. My remarks in Part I that the viewpoint of one studying drillings is different from that of one studying outcrops in such a basin as Lower Michigan must not be forgotten. The gaps due to discordances and disconformities are liable to be much greater; the emergence sandstones less at the outcrop that at the center of the basin. Both the St. Peter and the Berea I take to be emergence sandstones in Michigan, and neither of them have been recognized as outcrops, though distinct in some drill records. The base of an emergence sandstone is probably a more definite datum plane than that of a submergence sandstone.

The greatest thickness of the St. Peter seems to be to the southwest. Just outside the state at Marinette, No. 2 well apparently gives 75 feet of it from 325–400 feet. But how rapidly it thins and how irregular it is, is shown by the fact that at Gladstone it was not distinctly recognized, and across the Bay de Noe perhaps represented only by a red clay shale, the weathered surface of the Calciferous dolomite. It seems to fill hollows in the eroded Calciferous quite as in Wisconsin. Farther east it is not known. The Pickford record is imperfect, and in the Neebish samples, if present, it is indistinguishable from the Lake Superior sandstone.

[1] Schuchert, *Science*, XXIX (1909), 630; *Bull. G.S.A.*, XX, No. 20.

[2] *Op. cit.*, Pl. 101.

12. *Trenton limestone.*—Under this head have been grouped, as appears from Foster & Whitney's map, and the text by them (p. 140, Hall and others) equivalents to the Chazy, Birdseye, Black River, and Trenton in its narrower sense of New York. We are thus including all the Mohawkian and the Chazy, the lower half of Schuchert's Ordovicic. Grabau would include all up to the Black River in his Chazyan or Middle Ordovician, and would also combine the Trenton with the overlying Utica. In a general way it is what Bigsby referred to (1823, pp. 195–96) as the "limestone of St. Joseph." He refers to its typical exposures on St. Joseph Island and figures characteristic fauna. He also gives an excellent lithological description, mentioning the characteristic "Birdseye," or as he calls it "knotty," texture of some parts.

Pleading that neither at top nor bottom do our dividing lines exactly agree in time with the New York column, Grabau would suggest a local name like Escanaba. But it is entirely unlikely that the dividing lines are exactly the same at the two ends of the Upper Peninsula—that is, on the Escanaba and St. Mary's rivers where alone it has been, or can be, studied. Still less likely is it that where it has been struck in deep wells at the other end of the state, it is the same. Yet all over this vast area the line of change to black shale (Utica) from limestone or dolomite is well marked and of practical importance. It probably represents not very far from the same time. In fact, why should not a change in sedimentation at this point be due to diastrophism involving an instantaneous or simultaneous change over a wide area, a general retreat of ocean due to a large drop in its bottom somewhere, both shallowing the sea and exposing the land to renewed erosion and so muddying the waters?

For subdivisions we may use the Green Bay wells:

Galena limestone, crystalline, granular	83
Limestone, fossiliferous 55 ft., white 8 ft., dark 9 ft.	72
Alternating blue and brown, crystalline, granular. With the dark base compare the Wisconsin oil rock	225
Sandy limestones, "quartz" 6 ft., limestone 44 ft., quartz 1 ft., limestone 24 ft., compare quartz sandstone at Marinette at 260–275 ft.	75
Wisconsin Trenton (Platteville?), blue shale and limestone	41
Blue shale 4 ft., black limestone 141 ft., limestone 19 ft., blue shale 4 ft.[1]	

[1] By a numerical slip in the *Annual Report* for 1903, p. 132, it is given as 41 ft.

At Marinette, too, the samples at 290 and 300 to 325 feet are shaly, blue, pyritiferous, and a well near Maple Ridge shows that this blue shaly base is persistent. Beneath it is a marked horizon for water. In the Neebish well, the bluish shalier base is distinct between 158 and 186 to 205 feet, but other correlations can hardly be made. I do not believe that we can yet tell where to draw the line between the Middle and Upper Ordovician on Grabau's latest plan, his Chazyan, and Trentonian-Cincinnatian-Nashvillian, nor divide into the epochs made by Schuchert, though possibly this blue shale may mark the culmination of submergence, the beginning of emergence. It is quite clear that the Trenton, as used in Michigan and generally in the West, corresponds closely with Clarke and Schuchert's Mohawkian, including whatever there may be of Chazy and Stones River (Lowville or Birdseye), Black River, and Trenton.

The section on the Escanaba River is said by Hall to be less than 75 feet (p. 144) and to include 15 feet near the top, gray, meagerly fossiliferous (p. 146). Rominger estimated it at 100 feet. But a close correlation of the various outcrops with well-sections has not yet been made. Until it is, it seems to be conservative in the matter of names.

While Escanaba limestone, suggested by Grabau, is a euphonious term, my impression is that it would be better to use Trenton, the old widely used term, in a broad sense and introduce Escanaba as applicable to some accurately defined subdivision. The triple division above suggested might perhaps be improved for paleontological purposes by transfer of a few feet. I think, however, that the occurrence of a sandy middle member, and especially a blue shaly lower, will be found widespread.

The Trenton limestone marks the culmination of Ordovician depression, when the land masses seem to have been fully buried far and near, while at the same time conditions for animal life were very favorable. As Limestone Mountain on Keweenaw Point shows the Trenton extended much farther than shown on Chamberlin and Salisbury's map (II, Fig. 129, Schuchert's map, 57 to 58). The thickness of the whole Trenton, including the Galena, is best taken from the Wagner wells (1903, p. 134) as 271 feet. The records do not indicate that it thins much to the east. Oil wells in Manitoulin

Island at Gore Bay report it 250 feet thick. I do not know any well in the lower part of the state that has gone through it, but in wells in northwestern Ohio it is said to be over 780 feet thick and in the Carmen well at Petrolia, 602 feet. While called a limestone, in this state it seems to be often dolomitic.

13. *Utica shale* (Eden of Ohio). 50–80 feet.—In many parts of the West geologists have consolidated all the shales over the Trenton as Hudson River, Cincinnati, or Maquoketa. In Michigan we seem well able to separate a black shale below, persistent and fairly uniform, varying in thickness from 50 feet at the north to about 200 feet at the south. It does not seem to be separated by disconformity above or below, and the conditions which produced it, widespread as they were, we may well expect to be universal in the sea in which it was formed. The correlations with the Utica or Eden of Ohio and Utica of western New York seem perfectly satisfactory. The base is well defined, but the line between it and the Lorraine above is not sharp and probably not consistently drawn, and may sometimes have been carried up to the Waynesville, especially as none of the wells are represented by samples every 25 feet or less. Generally the Utica and Lorraine have been grouped together and mapped with the Richmond, also as the Hudson River (Cincinnatian or Maquoketa).

14. *Lorraine or Maysville.*—We must often include with Lorraine the Richmond as well as the Maysville, which we cannot sharply separate from this or the Medina. The beds are abundantly fossiliferous, and their correlation with the "blue limestone and marls" of the Cincinnati and "upper beds of the Hudson River" is attested by Hall, Winchell, and Rominger. The Wagner well shows for the blue beds 150 feet and more, the Pickford well 215 feet, and the breadth of the belt assigned to the Lorraine and the Utica on the maps with a dip of 40 to 60 feet to the mile would indicate 350 to 450 feet. They probably thicken rapidly to the south at first, as Cheboygan well would indicate over 343 feet, while on Manitoulin Island there is but 285 feet between Niagara limestone and Trenton. At the south end of the state the records indicate about 600 feet of shaly beds to be divided between the Utica, Lorraine, Richmond and Medina, say 200 feet Utica, 250 Lorraine, 150 Richmond and

Medina. The Lorraine, therefore, appears to be fairly uniform in thickness throughout the Lower Peninsula except at the extreme north end, where it may have been eroded. The Cheboygan well shows largely limestone. The line at the top is quite uncertain. I may have included beds corresponding to the Indiana Richmond.

15, 16. *Richmond and Medina transition beds.*—This is the period of deposition of coarser matter and residual red clays formed from limestone during a period of continental uplift. Ulrich[1] would class the Indiana Richmond with the Medina and the whole group not with the Ordovician but with that above. I do not doubt that he is right. There is, however, a convenience in grouping it closely with the shales below, since it is often lumped together with them in oil-well drillings. If formed in a period of continental uplift we need not expect to find it spread so far onto the continental shield. Except for a few (26) feet doubtfully assigned to the Upper Medina by Holt and Winchell, it has not been recognized in outcrop, nor was the characteristic red facies noted in the Pickford well. At Limestone Mountain the interval from Trenton to Niagara is not exposed, no Medina has been found. The Cheboygan well shows that though absent or nearly so along the outcrop it increases rapidly to the south, since Alden and I would assign to the Medina the beds pierced by that well about 142 feet of red and green shale. During this period, Richmond to Medina and Clinton, there was a relatively ample supply of iron to the sediments, as the Clinton ores (found in Wisconsin also) show. Cummings has recently described the different horizons in southern Indiana very carefully[2] and agrees with Ulrich that the later Richmond represents the Medina, the culminating of an uplift. With this, Michigan facts are entirely in harmony, though Schuchert brings in a big oscillation in the Richmond for which I have not noted any evidence.

In wells of the region near Ohio, red beds at this point of the column can be identified, but what is noteworthy and significant, the records do not closely correspond. For instance, at Monroe 685 feet and at Toledo 675 feet above the Trenton is the last distinct dolomite sample (Clinton ?), with red and green shales below, whereas

[1] *Science* (1909), 630.

[2] *Thirty-second Report Indiana Survey* (1907), 621, 687.

at Strasburg a few miles off at 534 feet only above the Trenton is dolomite with a very red rock beneath it. No such rocks are clearly identified in the wells in the southwest part of the state, and probably were never deposited. A simple explanation would be that there was some erosion of the underlying formation here as well as along the north border and that the red and the marine part of the Medina was much restricted. Grabau has suggested that these red beds are not marine and includes the Medina as Clinton. There seems, however, to be a gradual transition from the beds below, rather than sudden uplift. Moreover, why, if wholly land beds, should they be restricted to the center and lower parts of the basin?

SILURIAN (ONTARIAN)

Some part of the beds just described may be Ontarian, as Ulrich and Cummings have said, with whose interpretation of the facts Michigan stratigraphy is in entire harmony. If so they should be classed as Medina, but as in many of the records of wells we have to include them with the shale group below, I have preferred to associate the description also.

The term Niagaran as used in Michigan includes, in mapping, Clinton to Guelph. In sections it has been used also in a slightly narrower sense, not including the Clinton.

Bigsby (1823) used the term Manitoulin limestone in an equivalent sense, giving its lithological character, organic remains, and geographic position clearly, but while he very clearly distinguished it from the St. Joseph (=Trenton limestone) and the Mackinaw (Dundee-Monroe=Helderberg in its original broad sense) limestones, he did not separate it from the shaly beds immediately above and below, which are indeed far from conspicuous in the outcrop. If we use the term Manitoulin, these limits may then be set to suit our convenience so long as the local equivalents of the Guelph and Lockport are not excluded.

As the Trenton marks the first, so the main mass of the Niagara (Schuchert's Louisville) marks the second, Paleozoic period of "epicontinental seas" of large transgression over the continent. The fact that Niagara is found in Limestone Mountain on Keweenaw Point, near Hazel Station of the Mineral Range Railroad, makes it

highly probable that all of Michigan at least was covered, and the freedom from land detritus makes it probable that the submergence was widespread, and that whatever land existed was low, and erosion mainly chemical. Elaborate subdivisions have never been made or mapped of the outcrops in the Upper Peninsula. Well-records, however, show toward the center facies that we may parallel with the New York Clinton, Rochester (Niagaran) shale, the Lockport limestone, and the Guelph dolomite, and besides this at least one fairly persistent sandy and water-bearing horizon, the Hillsboro sandstone.

17. *Clinton.* 0–130 feet.—It seems to have been well into Clinton time before that part of the state where now is the Clinton outcrop was submerged. While all writers recognize that the Clinton facies exists in the Upper Peninsula, Rominger does not consider it worth dividing, and none have tried to map it separately. A. Winchell makes it but 3 feet thick. On Manitoulin Island there may be 31 feet. Hall gives, p. 154, Sturgeon Bay, this section:

	5	light-gray Niagaran with *P. oblongus*	10
Possibly Clinton	4	thin calcareous and siliceous beds 6–10	25
	3	shaly and mixed beds Cytherina 15	
Possibly Medina	2	heavy-bedded greenish-calcareous and argillaceous limestone with chert nodules	6
	1	soft, brittle, greenish	20

The Cheboygan well shows some 60 feet which may be placed here.

In the southeastern part of the state nearer New York the Clinton is more surely identifiable.

The Port Rowan, Canada, well shows 75 feet under the Rochester.

Argillaceous dolomite seems to be the dominant rock. Water and gas are often struck in it under the Rochester shale. At South Bend there are argillaceous dolomites 1,180–1,300 feet. At Dowagiac a brownish-red carbonaceous limestone at the bottom (1,760 feet) may represent it. At Kalamazoo is an interesting section suggesting a land surface near 2,230 feet.

18. *Rochester shale.*—Above the Clinton a shale is generally identifiable in the records; whether it is the Rochester shale or at times part of the Clinton may be a question. Though persistent it is never very thick—usually 30 to 20 feet.

The Kalamazoo section of which there are samples is very interesting (but there is always the possibility of misplaced samples), and may mean that this part of the state was out of water at intervals up to the Louisville or Guelph epoch and that *after* the Clinton there was a minor re-emergence, as at the time of the Richmond Medina beds. The succession is the same, limestone, shale, and red beds, only on a smaller scale. It is also worth noting that the shale is "red" in the Carmen well; Petrolia, also "red rock" occurs just above this slate at South Rockwood (1,285–95 feet deep) near Detroit, and the Strasburg sample on top of the Clinton suggests emergence. Toward the end of the time of the Rochester shale then the shore-line probably passed through Kalamazoo. This is the more interesting because just southwest in Illinois[1] the Clinton is usually about as thick as in Michigan and is followed by a long break in sedimentation. Thus we may imagine that region emerging at the close of Clinton and staying so until after the Guelph, while Michigan did not emerge at Kalamazoo until after the Rochester shale and then at most during the lower part of the Lockport Guelph time only.

The peculiar feature of this time seems to be an oscillation or tilting, the Clinton extending more to the south, the Rochester and Niagara opening up to the north, and from the time of the Richmond Medina until after the Rochester shore-lines seem to have been in Michigan, with the continental shield fairly high. (Compare Schuchert, Pls. 64 to 66.)

19, 20. *Lockport and Guelph dolomites* (Manitoulin).—The Lockport and Guelph have different fossils but have never been separated paleontologically in Michigan. The upper limit against the Salina or Monroe is marked only in this way, that the Guelph is peculiarly hard and peculiarly white. One cannot absolutely depend upon the presence or absence of anhydrite as a dividing line. It is convenient at times to separate off the lower, less white and uniform part as Lockport (Louisville). The total thickness of the two at maximum seems fairly persistent and uniform, across the lower part of the state 350 to 270 feet. At the north part of the state it appears to be thicker. The well No. 2 St. Ignace gives just 600 feet, as a Cheboygan.

Extreme whiteness of the upper part, occasional sand grains

[1] Savage, *Illinois Survey, Bull. No. 8*, 108.

(1 per cent or 2 per cent, as though wind-blown) in the dolomites, and occasional beds of sandstone are characteristic all over the state.

It is exposed only in the Upper Peninsula. It forms the shore of Lake Michigan and Lake Huron in a continuous ridge which rises to the north almost at the dip of the beds, which is about 50 feet to the mile, from the lake level 580 feet A.T. in somewhat less than 10 miles to an elevation of about 800 feet A.T. Here and there it outcrops and very often the soil over it is thin.

While as a whole it is dolomitic, there are horizons, notably that of the Fiborn and Rex quarries, which run nearly pure calcium carbonate. They probably occur in the lower part beneath the Guelph.

The absence of sediment and the absence of iron and the fact that it is succeeded by a salt series suggests that the climate was not a very rainy one.

21. *Salina* (or Lower Monroe).—The term Monroe was introduced by me in 1893[1] to 1895, and as at first used without definition did not include all the beds down to the Niagara. In my later and more formal definition (Vol. V) I made it practically include all the Silurian above the Niagara, having found it impracticable to separate the Salina from the beds above. The difficulty still remains. The last salt bed is not always at the same horizon.

According to Grabau, there should be a marked hiatus and disconformity between the Niagara and the next overlying beds in Monroe County. The thickening as we go north, which is rapid and very great, would then be practically by addition at the bottom of beds formed during this disconformity.[2] Now, comparing wells at Britton, Milan, Romulus, and Wyandotte we do find an increasing thickness, and five feet of rock salt at Milan seems to be almost directly above the Niagara, whereas in Wyandotte there are 275 feet of dolomites below the rock salt and above the white dolomite. The rock salt at Milan is 717 to 722 feet below the base of the Sylvania, and *may* be continuous with a bed of 790 to 900 feet below it at Wyandotte, 1,080–1,190 or 1,235 feet. Again, as we go north the salt beds seem to occur higher up. Gypsum (anhydrite) certainly occurs

[1] *Report* for 1891–92, 66.

[2] *Bull. G.S.A.*, XIX, 554. Compare also Schuchert, *op. cit.*, Pl. 68.

above the Sylvania, and it is not very easy, though it may be possible, to separate off a part of the Monroe as Salina. The thicknesses given by Grabau for the Monroe below the Sylvania add up 500 feet. Salt occurs below the Sylvania usually within 450 feet. To the southeast on the Cincinnati anticlinal the salt disappears.

It is difficult to draw the upper line of the Salina in cases where no salt exists, and that is the excuse for considering the Salina as perhaps Lower Monroe. We have only lithological grounds to identify it with the New York Salina, and it is altogether unlikely that the top can be drawn consistently on such grounds. One can go only 400 feet below the Sylvania sandstone if present and then take the top of the nearest salt or gypsum bed. This gives fairly consistent results.

In the southwest part of the state, where no rock salt occurs, and all the Dundee and Niagara together do not amount to the Upper Monroe alone on the east side of the state, there was perhaps more elevation and more exposure to erosion.[1] The samples from 1,490 feet to 1,730 feet at Kalamazoo represent the Upper and Middle Ontarian and are dolomites with more or less anhydrite and quartz and *some red clay* at 1,650 feet.

Now if here was, part of the time, shore for land southwest, we should expect to find still less deposition at Dowagiac. I am inclined, therefore, now to raise the Niagara at Dowagiac even more than I did over Wright in Vol. V, to wit, up to 1,100 or 1,135 feet, taking in all the light limestones. The Dowagiac Monroe would then be only 100 feet (1,000–1,100) dolomite with 10 to 30 per cent anhydrite and quartz. If so, then the Niagara would come in the white limestone at the base of the Niles well and the Monroe between 625 and 985.

The outcrops near Milwaukee—the Waubakee dolomite of Alden, Lower Helderberg of earlier writers—are probably higher than Salina. At Ludington and Manistee, however, rock salt was struck, but apparently there is but one layer.

There is some question about a Ludington well put down by J. S. Stearns, with samples suggesting the absence of the Dundee there, and the presence of the Salina. But this agrees with Schuchert's Plate 75, and as we find over across the lake at Milwaukee

[1] Schuchert, *op. cit.*, Pl. 69.

the Traverse and Monroe (Milwaukee and Waubakee of Alden) represented, and not the Dundee or Corniferous, it is more natural to suppose the Dundee absent here also. The irregular red and rusty character of the Dundee samples at Manistee and the way it varies in the wells also suggests a deposit near shore frequently interrupted by disconformities.

Of the Frankfort well no samples have been kept, but I am told that the wells were put down deep enough to have reached the Niagara (1,800–2,200 feet) without striking rock salt and without reaching a very strong brine. So that it is likely that this was just outside the Salina sea like Milwaukee, while Ludington and Manistee were just inside.

St. Ignace and Cheboygan wells showed the New York Salina red and blue shale facies. We have therefore good reason to believe that at the close of the Niagara or Guelph the sea-level fell so that all of the southeastern portion of Michigan was above it. This begins the emergence between the Silurian and Devonian. If the salt deposits were laid down as a non-oceanic Caspian sea, we may suppose red shales like those of St. Ignace were deltas of a stream that fed it, and that the inland sea extended to the New York Salina where were other deltas from Appalachian streams. The bottom of the Salina sea should, however, have been below sea-level, like the Dead Sea at present, for we find just after Sylvania time, and at the beginning of the Devonian, incursions of ocean water and animals. Now, the top of the Niagara below this is not less than 1,200 feet at Wyandotte, and below the top of the Salina 700 or 800 feet. If then the top of the Niagara at Wyandotte was above sea-level after the Guelph, either the continent was raised something like a thousand feet, or there was warping of the crust during Salina. There was warping of the crust during the Upper Monroe, and since, but not, I think, enough to alter the fact that Lower Michigan has been permanently a basin. Any such emergence of the continent should have left traces in the sediments derived therefrom, sandstone or red shales derived from residual clays. No such beds are known to me. The Salina appears to me rather the result of but slight emergence, which grew more marked but irregular during the time of formation of the top of the Monroe.

As shown by various records, the Cincinnati anticlinal had formed and was out of water and divided the Salina sea[1] into two basins, connected perhaps by a channel through Canada between Goderich and Petrolia, north of Wallaceburg and Port Rowan, the one the New York basin, the other the Michigan.

The earlier salt beds appear to be heavier. A great many records report salt coming directly on top of "lime." Now this does not mean much, for without samples and careful observation one cannot discriminate limestone, dolomite, and anhydrite (anhydrous sulphate of lime). In many cases where samples have been saved, under the salt comes anhydrite and a good part of that which is reported as lime is really anhydrite. But in some it appears as if salt really did lie directly on dolomite. An explanation is suggested in my report for 1908, dependent on a supply of alkali water replacing the base calcium by sodium, making sodium chloride more likely to precipitate but retarding precipitation of calcium sulphate.

22. *Lower Monroe.* Bass Islands Series. 365–500 feet.—This is a series of dolomites with beds of oölite like those around Great Salt Lake, as Sherzer has shown. The cessation of salt-making may simply show that the climate had so changed that there was enough of a supply of water to keep the more soluble chlorides from forming. Or there may have been some light crustal shifting opening an outlet. There is in Michigan no sign of structural break between this and the Salina.

Grabau subdivided as follows, provisionally:[2]

d.	Raisin River dolomite, zone of *Whitfieldella prosseri* with oölite zones	200 ft.
c.	Put-in-Bay dolomite, zone of *Goniophora dubia; Leperditia* also....	100 ft.+
b.	Tymochtee beds? (Winchell Ohio).....	100 ft.±
	Relations unknown; quite likely equivalent to some other division, shaly and thin-bedded	
a.	Greenfield dolomites, Northern Ohio.....	100 ft.±

The fullest lithological descriptions are given in the Monroe County report by Sherzer, VII, 46–100. Fossil lists are given by Grabau, *Bull. G.S.A.*, XIX, 545–49.

Oölite and sandy dolomites and dolomites with anhydrite which is primary, acicular or gashed dolomites in which the hollows were,

[1] Schuchert, Pl. 70, somewhat modified.

[2] *Bull. G.S.A.*, XIX, 554.

as Kraus has shown for Monroe County, probably filled by (strontium sulphate) celestite, are characteristic rocks both in Monroe County and in the Upper Peninsula. A series of wells at intervals of but a few miles at most have penetrated this series from the Ohio line to Port Huron. It outcrops and is exposed again near St. Ignace and Mackinaw City and the islands north of Beaver Island. It probably touches the Wisconsin shore near Milwaukee, and is reached by a series of deeper wells along the western side of the state. A list of locations will be found in the report for 1908.

As the total thickness from the base of the Sylvania down to the salt shown in numerous sections runs only from 337 to 400 feet at the outside, Grabau's estimates of the thickness of the subdivisions cannot be added. It is very often impossible to make lithological subdivisions. A bed of sandrock often occurs under the main Sylvania sandrock a short way. The Waubakee dolomite fossils in Wisconsin most suggest the list of the Raisin River and Put-in-Bay beds, and I think there is reason to believe this series more widespread and persistent than the series above or below. The salt series below certainly does not extend so far either to the south or to the north. To the southeast down in Ohio, where the Sylvania sandstone is very thin and the overlying beds between that and the Devonian limestones easily overlooked, this lower Monroe is still persistent. The fossils reported from Milwaukee and from the Upper Peninsula by Rominger[1] are Lower Monroe rather than Upper Monroe forms.

Finally as we trace the beds from the thinner "Helderberg" or Monroe sections of Indiana toward the thicker sections, between Algonac and Alpena, the addition seems to be of beds above and below to a nucleus of Lower Monroe which remains fairly uniform in thickness. But there is this difference as we trace the section north along the Lake Michigan shore from that which happens as we go east toward the Cincinnati anticlinal. In the former case the Traverse (Hamilton) thickens, but very little is seen of the Dundee beneath—between it and the Monroe—in fact, there does not appear to be much added to the Monroe itself. The explanation would seem to be that for a good part of the marked erosion intervals (Waubakee or Helderberg) between Niagara and Monroe and again between the

[1] *Michigan Geol. Surv.*, I and III, 28.

Monroe and the Traverse (Milwaukee or Hamilton) the east or Michigan side of Lake Michigan was out of water and the Wisconsin post-Niagara uplift was fairly uniform from south to north. On the whole, the south seems to have been first to emerge (since there is more Niagara at the north and the seaward opening was to the north). The Salina sea was left to deposit salt. The recession or submergence during the Monroe may have been uniform. Whether the next emergence began sooner at north or at south one cannot tell since there is so decided an erosion unconformity.

A small percentage (1 to 5 per cent) of sand found in the Monroe dolomites may have been wind-blown from exposed beds of sand in Wisconsin. Passing northeast we find the Lower Monroe persistent. I am inclined to think, therefore, that the Michigan seas of Schuchert's Upper Siluric maps should open to the north much more.

At Port Huron the Lower Monroe is (1,215–1,555 feet) 340 feet and making a considerable jump to Goderich, Canada, we find between the limestone group and the salt 364 feet. This persistent thickness is an argument that between Monroe County and Goodrich was continuous deposition and that we have a complete section here. At Grand Lake in the Alpena Land Co.'s well, we find the limestone coming down somewhat farther and very thick. At Alpena the whole Monroe appears to be only about 713 feet, but there are discrepancies in the depth at which salt is said to occur at the different wells around Alpena that may be due to dislocations of the Monroe before the Traverse.

There seems to have been a pre-Traverse dip from Alpena north, enough to counterbalance the present Traverse dip the other way and in that direction was limestone and the open sea.

To the east then the submergence of the Monroe was longer, the emergence at the close delayed, and as we shall see, intermittent, and a land-mass formed to the south during the Upper Monroe.

23. *Sylvania sandstone.*—30 to 440 feet thick as sandstone, 170 feet as limestone. This, the Middle Monroe formation, is easily described. It has been found only along the flank of the Cincinnati anticlinal as a well-defined bed. It thins toward the outcrop where it is between 50 and 100 feet thick. It is thickest in a line through Milan, Ypsilanti, and Royal Oak. It probably skirts the Cincinnati

anticlinal rather narrowly, for it is relatively thin at Britton, Ann Arbor, Mount Clemens, absent at New Baltimore, though present at Port Lambton and Marine City, and absent at St. Clair, but present at Port Huron.

Grabau and Sherzer are inclined to consider it aeolian. But the way the grains of sand occur in the dolomite or limestone as in Port Lambton (and in a series of records like those at Marine City [Vol. V], we find it shading into the dolomites) its fairly regular variation in thickness, similar at similar situations[1] on the Cincinnati anticlinal, growing thicker to the line of thickness above mentioned, suggest that if they were wind-transported they were water deposited. Of course, near the outcrop it may be more aeolian. Lithologically it is a pure (99 per cent) quartz sand of the highest grade of glass sand as white as sugar. The nearest like it of recent sands that I have found is one from Florida. Its extreme freedom from iron is not characteristic of desert sands. On the other hand, it seems to have a characteristically fresher water (stronger in sulphates) than the beds below.

The disconformity with the beds below which Grabau mentions is not marked, though there are red sandy-looking beds at about that horizon in a few wells. The disconformity above is most marked and, as Grabau has pointed out, a new fauna appears of puzzling affinities. It seems that in many places during the whole time of the Lower Monroe and the Middle Devonian the American continent was out of water, and the disconformity marking this period of emergence is the well-defined and accepted line between the Silurian and Devonian. This applies to Milwaukee and western Michigan. But the great basin of Lower Michigan was not lifted altogether out of water. The warping which caused the emergence lifted up the Wisconsin land-mass and also the Cincinnati anticlinal, and the Sylvania sandstones were formed as emergent sandstones along a shore not altogether unlike those from Chicago around to New Buffalo today. It was partly aeolian, but there is reason to think that much of the wind-blown sand found its final resting-place under the water, building a sandy shelf out from the shore.

[1] Compare Dundee, 60 to 253; Morton Salt Co., 65 to 262; Solvay, 95 to 415; Wallaceburg, 100 to 1,100; Port Lambton, 50 to 1,250.

But the emergence this time was not a mere recession of the sea-level. There was an Appalachian warping and gentle folding extending clear to Michigan, for as Grabau has pointed out, not only is there a disconformity of the Sylvania and overlying beds, but both together were folded and eroded before the Upper Helderberg was laid down, both around Alpena and to the mouth. One result of this was to permit an incursion from somewhere (judging by the thickening of the limestones from north of Alpena) of the first Devonian-looking fossils known, as described by Grabau. He tells me the same things come from the Saskatchewan.

It seems clear, comparing the records of the various wells, that to the northwest the Sylvania is replaced by a series of limestones.

Take the large group of wells at Marine City reported in Vol. V. In all of them at about 1,000 to 1,100 feet down, and about 500 to 600 feet above the first salt, 300 feet or so above a well-marked gypsum bed (which may be really the most fitting place at which to draw the top of the Salina) we find from 60 to over 100 feet of sandstone, often calcareous and passing into a sandy limestone or arenaceous dolomite, like the top of the Lower Monroe Raisin River beds. The same horizon is plain in New Baltimore 940–1,275; St. Clair 1,050–1,270, and Port Huron. There can be hardly a doubt that this corresponds to the Goderich Group III of Hunt, and so presumably to the Sylvania and part of the Upper Monroe. As usual *passing from the outcrop the unconformities* seem less. In its limestone facies it is impossible so surely to assign a thickness, but it seems to be about 170 feet. How much of this should be attributed to a thickened base of the Upper Monroe is a matter for further research. The fairly uniform thickness for Middle and Upper Monroe from Lake St. Clair to Alpena suggests no appreciable disconformity in this region. So far as one can judge the Upper and Middle Monroe are absent on the west side of the state. Even around Mackinaw and at Cheboygan there are no indications of them known to me. They are not shown on any of Schuchert's maps. I am not so sure they should not be placed on Plate 72.

24. *Upper Monroe.* Detroit River Series (275 ft.).—This series seems to have been deposited in a long, narrow trough at the very end of the Silurian at a time when most of the continent was out of

the water and much progress had been made toward the evolution of the Devonian forms. Just as in New York higher and higher horizons of the Eo-Devonian rest to the west on the Salina and water lime, so in Michigan to the southeast and south higher and higher horizons of this formation rest on the Sylvania. It is also true that the Corniferous or Dundee rests on various members of this. The Corniferous (Onondaga) above is unquestioned Devonian. The Monroe below the Sylvania will, by general consent, be classed with the previous period. But the Sylvania has often been called Oriskany and the fossils of beds above are remarkably like Hamilton forms, while the very top of the Lucas dolomite has been generally taken to be below the Devonian.

If, with H. S. Williams, we place the base of the Devonian at the Oriskany and class the Lower Helderberg beneath as Silurian (Ontarian) as used to be common (compare the 1892 edition of LeConte with the latest) we can then surely place the whole Monroe with the Silurian as I did. Canadian writers have generally grouped the Sylvania as Oriskany.

But beneath the Oriskany comes the Lower Helderberg series of New York 300–400 feet[1] and Pennsylvania 600 feet, and in Europe stages E and F, and the relation of these to the faunas is a complex problem of paleogeography. After the Salina (all up) was there a see-saw—first the Michigan trough down (Upper Monroe), then up, and the New York Helderberg down? This is the view accepted by Grabau. Or is it possible that at the time of the Sylvania the Michigan basin was so separated from that of New York that the two could have separate faunal developments at the same time, the New York receiving precursors of the Corniferous, Michigan of the Hamilton, while somewhere around there lingered relics of the Silurian faunas which re-established themselves when the old anhydrite- and dolomite-forming conditions returned in Michigan? This would imply that on Schuchert's Plate 72 a long sound of Upper Monroe should extend, opening to the north.

On the whole, the greater break as well as the most widespread, and therefore the one best fitted to mark the beginning of the Devonian, seems to be that above the Detroit River series. For there

[1] Schuchert, *Bull. G.S.A.*, XI (1900), 270; XX.

appears to be not merely a disconformity as between the Detroit River and the Salina but an actual unconformity, so that the Detroit River beds were folded before the Dundee and Traverse were laid down. Such a folding is indicated by the fact that while at Alpena there is[1] a dip of the surface beds 42 feet to the mile to the southwest this does not seem to be the case for the lower beds of the Monroe. The salt is as deep to the north. Again, along the St. Clair River in the Devonian there is an anticlinal near Port Huron where the oil wells are in the Traverse (Hamilton). But the Monroe beds do not follow this fold The salt runs more nearly on a level. Again, around Detroit in Wayne and Monroe counties, Grabau has described how the Dundee of the Devonian lies on various beds of the Monroe. For the present, therefore, it will be well to keep the line between Devonian and Silurian as heretofore and as Grabau wishes, remembering that with the line so placed, a very Devonian-appearing fauna already existed during the time of the Detroit River beds, and that, as in New York, between the Helderberg and the Oriskany[2] there is an unconformity and a more marked one prior to the Cobleskill Rondout, so it is with the Detroit River series, which from a structural point of view is closely allied to the Helderberg.

At the salt shaft, and near by, the subdivisions are, according to Grabau and Sherzer:

146		
	180	1. Lucas dolomite (with Cylindrohelium profundum) (200 feet+) with sulphur and gypsum.
326		
	9	*c.* Amherstburg dolomite (with Panenka canadensis) transition to Lucas—20 feet.
335		
	38	*d.* Anderdon limestone (with Idiostroma nattressi and a fauna like the Hamilton).
	40	50
373		
	47	*e.* Flint rock dolomite (with Syringopora cooperi).
	50	
420	150 feet+.....	
	Sylvania sandstone beneath.	

[1] *Report* for 1901, 67, and Pl. VII.

[2] See Grabau, *Geology and Paleontology of the Schoharie Valley*, 179; *New York State Museum, Bull. 92.*

It is next to impossible to trace these largely paleontological subdivisions in the wells, especially the difference between Amherstburg and Anderdon. But the tendency to a dolomite top, with sulphur reduced from gypsum and anhydrite, and limestone lower can be plainly followed.

Above the undoubted Lucas either as an extension of the base of the Dundee or as a still higher member of the Detroit River series (which it would be interesting to compare with the New York Helderberg) was an intercalation of limestone in the Lucas which did not reach as far as New Baltimore. By the time we get to Alpena, limestone occurs at various horizons. There is clearly a tendency to replacement of dolomite by limestone toward the north in the direction probably of the open sea. The Michigan Monroe seems to have been, like the Black Sea and Caspian, turned northside south.

At the close of the Monroe the state was so elevated that slight folds which occurred at the same time could be planed off, and the underlying formation in numerous places from Mackinaw to Monroe County, made into a dolomite conglomerate, calcirudite. So far as we know it remained above water during the opening stages of the Devonian Helderbergian. There is distinct reason to believe that *this* uplift was not a mere rise and fall of the sea strand produced perhaps by disturbances thousands of miles away like the earlier changes in Niagara time, but a tilting by which the west was more elevated than the east and a certain amount of folding took place. The Limestone Mountain fold on Keweenaw Point may have taken place this early. The Sylvania uplift seems to have been decidedly most at the south, opening up and depressing the land at the north. By the close of the Amherstburg the effect of a new uplift made itself felt in cutting off the northward connections and the conditions for formation of dolomite and anhydrite were re-established and with them the Silurian fauna. The same disturbance that cut Michigan off once more may have opened up New York to the Helderbergian, so that while the Coeymans and Port Ewen beds were forming in New York, 300 or 400 feet in all, Michigan was mainly out of water, and not until the Schoharie (Hall in Foster and Whitney, II, 225), did deposition that has been recognized by its fossils begin in Michigan.

DEVONIAN

25. *Dundee limestone.* 200 to 253 feet.—This formation—the Corniferous or Onondaga nearly—is full of fossils which have been described by Hall, Winchell, Rominger, Schuchert, Grabau, and others.[1] On the east side of the state between the blue and black shales that may represent the Bell or Marcellus and the first dolomite, which seems to be generally the top of the Silurian (of course, there may be a puzzling dolomite conglomerate at times) the formation can be traced persistently. It is very uniformly a high-grade limestone with only a small percentage of magnesia, not infrequently over 98 per cent $CaCo_3$, light colored, or brown with oily matter, containing a water relatively high in sulphates, relatively weak and strong in H_2S, and generally hard. It is sometimes, not always, cherty or "corniferous." Beginning with a thickness of an even 100 feet in the southeast corner of the state, it thickens slowly to Port Huron. Going west and north it at first thickens until it gets its full thickness of about 250 feet, and then begins to thin, as I now believe.

For instance, the Niles well on p. 280 of the report for 1903 may be interpreted as having only 12 feet of Dundee and then entering the Monroe, and that in Vol. V as (the Oriskany being at 540 feet) having but 40 feet, and all these wells in the southwest corner as striking through from some part of the Traverse corresponding to the Alpena limestone into the Monroe, the Dundee being omitted, agreeing with Schuchert's map, Plate 75.

As we go up the Lake Michigan shore northward it is apparent that the Traverse expands to the thick 600-foot section found in its northern outcrop, while the Dundee does not increase so much. The top thirty feet and other places are sometimes quite sandy and often cherty. It is not often sandy on the dividing line between it and the Monroe.

Throughout my work in Vol. V and the annual reports I have considered all the Dundee as a limestone and this has given consistent results. Four miles east of Mackinaw City, in a section where I thought I found the Dundee directly overlying magnesian limestones of the Monroe, Grabau found in the top layers of the magnesian beds a

[1] *Annual Report* for 1901, and *Bull. G.S.A.*, XVII (1901), 719.

typical Schoharie fauna, agreeing with Hall's determinations on Mackinac Island 50 years earlier. We must then grant the occurrence of magnesian beds near the base of the Dundee. It would be strange if overlaying a magnesian formation the base were not magnesian. The paleontological and structural dividing line may be a few feet beneath the lithologic line which I have had to use.

26. *Traverse* (Hamilton and Marcellus, Erian of Clarke and Schuchert, Delaware[1] of Ohio). 600 feet.—As this group is much thicker and better exposed in the north end of the state and its very existence along the south line of the state has been doubted, we begin our description from the north where it outcrops on Grand and Little Traverse Bays, and thence is frequently exposed around to Alpena and Thunder Bay, and is nearly uniform in thickness (600 feet with a basal shale, Bell shale, 80 feet, which corresponds to the Marcellus and is persistent throughout the state).

Grabau gives:

Chert beds	45–50	Naples goniatite fauna at top
Petoskey limestone	360	Stromatopora and buff magnesian
Acervularia beds	110	Bryozoa beds
Bell shales	80	
	600	

When we get to Port Huron, nearer the Cincinnati arch, it seems to have shrunk to 330 feet or so. Thence down to the Ohio line it tends to shrink especially toward the axis of the arch. But the *marked black or blue shale base persists.* Hence there is reason to suspect that the loss is mainly by removal of the top. This would imply that our early Traverse is Schuchert's late Hamilton, Plate 76. There is a fairly persistent division to which the drillers apply customary names.

Cooper's 2. Petoskey limestone. The "top lime" 85± (sometimes pyritic at its top).

Cooper's 3. The "top soap rock" 150±.

Acervularia beds. "Middle lime" 4–15. Never thick, but persistent, the Encrinal limestone?

Bell shales? "Bottom soap rock" 65. Darker than the other.

[1] Sandusky has been discarded.

There is good reason to suppose that during *late* Traverse there was some emergence, while the line between Dundee and Traverse does not appear to be marked by a notable unconformity in Michigan. We find also in New York the closest affiliation in deposition between Onondaga and Marcellus. The supposed unconformity at the top and maximum depression at the base of the Traverse is in harmony with the description by the Wisconsin Survey (ii, 397) of the beds there as early Hamilton.

27. *Antrim shales.* (Senecan, Genesee?, Portage and Chemung of New York, Ohio) Huron, Chagrin, Cleveland, and Bedford. 480 to 140+ feet.—There is good reason in the thinning of the formation and in the irregularity and reddening of the top to believe in an elevation south of Michigan toward the close of the Traverse (Hamilton). But in Iowa, too, the Upper Devonian is said to be unconformable on the Middle. At the base of the Antrim shales on Thunder Bay, Grabau found the Naples goniatite fauna which would imply, perhaps, that the Antrim black shales though lithologically like the Genesee were really somewhat later, and the Genesee missing.

This horizon is struck very widely. The full thickness is not less than 340 feet. In order to get consistent results and thickness one must recognize that the transition to the Berea Grit is gradual and a great thickness of Berea Grit or strata ascribed thereto is at the expense of the Antrim. The Antrim consists mainly of shales, black and bituminous at the bottom, then blue, and at top, where it passes into the Berea Grit, or the horizon thereof, red or interstratified with sandstones and gritty.

To put the base of the Carboniferous at the base of the Bedford we should have to split the Antrim in a very impracticable way, though we could readily enough follow Ulrich's suggestion and place it lower. It is noteworthy that just as the Sylvania is confined to the east side of the basin along the Cincinnati anticlinal, so is the Berea Grit, and when the Berea Grit does not appear, then the upper strata of the Antrim have a red facies like the Bedford of Ohio, or the Richmond top to the very similar Lorraine. This red facies is, it seems to me, very likely due to exposure to the weather. Where the Berea Grit is *well* developed it is, I believe, never found. It,

therefore, may indicate the uplift generally taken to mark the close of the Devonian and beginning of Carboniferous. The upper part of the Antrim is blue rather than black and frequently there are beds of sand and grit. There is generally at least 100 feet of the bottom black shale, but since the blue and black shales alternate at times, records may or may not show the Cleveland Chagrin and Huron as one solid black shale, or may overlook the Cleveland and count everything down to the Huron as blue shale.

MISSISSIPPIAN

28. *Berea Grit* (or sandstone[1]). 273 feet.—This is an Ohio formation and has never been seen at the surface in Michigan, but may be traced very well along the flanks of the Cincinnati anticlinal, from near Adrian north. Westward it seems soon to disappear and to be spotty in occurrence. Eastward it may well have once been continuous with its Ohio outcrops. Continuous past Ann Arbor and Pontiac and Birmingham, Romeo, Utica, and Berville to the southeast corner of Sanilac County it may be followed around the Thumb in wells put down to tap its brine to Bay City. From Bay City it may be traced north to Harrisville, near which it comes to the under surface of the drift. It thickens gradually from about 40 feet until it is thickest near its western margin (over 300 feet). Then it disappears suddenly. The brine is exceptionally salt, even near the surface, and unusually free from sulphates.

The sandstone is generally fine grained, micaceous, and overlain by a black shale (the Berea or Sunbury shale).

Now, if we take the Alma, Bay City, and Caseville wells and figure from the top of the Marshall as a datum we shall have the form of a deposit formed along a shore facing east and running nearly north and south through the center of Michigan (compare Schuchert's Pl. 78). It is also true that it is coarser where it is thicker and not so pure—more of a fine-grained grindstone to the east.

This points to a marked line between Carboniferous and Devonian. We have something like the same question that arises as to the red Richmond shales mentioned above, but there is a marked difference in that above the Berea Grit we do not pass into limestone like the

[1] Compare Oneonta Chemung and Catskill.

Clinton limestones, but back into black shales, like the base of the Antrim, the Berea, or Sunbury shale.

I am inclined to believe there was originally less sulphate in the brine and that would point to a less arid climate,[1] and with that the black shales and greater abundance of mud are in agreement. At any rate the Berea Grit seems to mark an episode apart from any *great* climatic change.

29. *Coldwater shale.* Part of old Waverly; Sunbury or Berea shale, plus Cuyahoga (which includes Buena Vista), plus Raccoon and part of Black Hand, perhaps; Orangeville and Sharpville? 1,000 feet.—The next series lithologically corresponds to the New York Portage and Chemung and is one largely of shales, which generally make valleys in the bed-rock surface and in a state so heavily drift laden as Michigan are rarely exposed. In Ohio there are two or three distinctions clearly made. The thickest, most carefully studied, and best exposed section is that of Huron County,[2] as follows:

Blue and sandy shales of Willow River and Secs. 2 and 3, Huron Township	172	
Black Hand of Ohio? in part		
Light House Point conglomerate, Herrick's I, Large fauna	4	176
Directly under should come the Raccoon, Herrick's Waverly shale fauna.		
Blue shales with carbonates of iron of Port Hope, Harbor Beach, White Rock to Forestville, with *Chonetes scitulus*, cf. pulchella, common throughout	720	896
Black Sunbury shale with *Lingula melie* and *Oroiculoidra newberryi* in Ohio	103	999
practically an even	1,000 feet	

The black shale base is very persistent when the Berea Grit comes beneath, and continues as at Alma and Grayling, even beyond its limits and is presumably the equivalent of the Sunbury or Berea black shale of Ohio. Like that it is a persistent and widespread horizon whose thickness is generally only 25 to 55 feet, averaging about 40. It is clear that in well records there must be some uncertainty as to whether we are dealing with the red Bedford or the red

[1] See analyses in Clarke's data of geochemistry.

[2] Vol. VII, *Geol. Surv. of Mich.*, Part 2, pp. 18–27, 247–52, Pl. I.

top of the Sunbury in wells where the Berea Grit itself is absent. In the extreme western part of the state, as at Dowagiac and Constantine[1] (one well only) less than 20 feet of red shale has to do duty for Bedford to Sunbury, and the Antrim beneath is thin. I think the red shale is the weathered top of the lower formation. It is conceivable that the Berea Grit once extended farther and has been eroded away. On the whole, however, it seems more likely that while the whole period Bedford to Sunbury was one of elevation, there were two times when the shore-line advanced farthest east—one just before the Berea Grit, one just after the Sunbury shale, correlative to the Buena Vista flags.

There has been a question as to whether it would be better to cut the Berea or Sunbury shale off from the Coldwater. But it was included in the original definition of Coldwater and has been recognized in Michigan only lithologically. It would seem best for the present to keep the term Coldwater as originally introduced to cover the interval from Berea Grit to Marshall, and use the Ohio terms Sunbury and Cuyahoga, Buena Vista and Raccoon for fitting subdivisions when possible.

Brines and sandstones seem to appear not really at the Berea Grit level but somewhat above, but correlations are largely guess work, as all of these sandstones are readily overlooked by drillers on the one hand, and none of them are thick, and sandy, salty streaks are liable to occur at various levels without question. Hard streaks are also liable to occur which are largely bands of iron carbonate, or they may be huge round kidneys, such as are known to exist.

The outcrops of the Coldwater were described by the first Geological Survey, Hubbard, and others, by Winchell in a long series of papers,[2] and by Rominger,[3] who calls it and the Marshall, the Waverly Group. It covers a considerable area.

On the western side of the state the Upper Coldwater (or possibly the Lower Marshall) about 300 feet below the top or 700 feet above the bottom becomes distinctly more of a limestone. At least that is one way to interpret the records.

[1] *Annual Report* for 1903, 281, 282.

[2] *Biennial Report*, 1860. See also Weeks in *Bull. 191* on Marshall.

[3] Vol. III, Part I, chap. viii, 67, 75.

Alma has sandstone, black shale, and limestone between 1,575 and 1,740 feet, i.e., 560 feet below the top of the Marshall, corresponding to Bay City 1,630 feet in the well of Vol. V (Atlantic Mill), 750 feet in the South Bay City well. This we may strongly suspect includes the upper part of the Coldwater down to Herrick's conglomerate 1, the Black Hand and Raccoon.

In the Charlotte well from 570–680 feet is sandrock, from 680–1,150 appearing to be shaly limestone, if the samples are representative. There are 350 feet below down to the Berea horizon. So at Jackson is a salty rock at 660 which, in Vol. V, I took to be the Napoleon, but I am quite sure that I was mistaken. This would seem to be an appearance of the Michigan series, or rather a Kinderhook facies and an incursion of the western Carboniferous during the Coldwater. It looks as though at about this time (that of the Coldwater and Marshall) the eastern side went up, the western side down, and that corresponds with what is known of the continent in a large way.[1]

The abundance of goniatites in the sandy beach-like beds of the Lower Marshall suggests that they were open to the western ocean, and we should expect an even more Kinderhook facies in the Upper Coldwater and Lower Marshall of the western part of the state. Unfortunately there is not the slightest chance of outcrops of this calcareous Lower Marshall or Upper Coldwater, but possibly some fragments of the fauna might be identified in the drift back of Ludington.

The Coldwater is an emergent formation and gradually passes into the sandier facies of the Lower Marshall; where to draw the line will be discussed in connection with the Marshall. The Coldwater appears to be nearly as thick even if more calcareous to the west, the total for Lower Marshall and Coldwater being always a little over 1,000 feet.

30. *Marshall sandstone* (Raccoon possibly, Black Hand and Logan of Ohio in part).—This formation was extensively studied by Professor A. Winchell who, in distinction from earlier writers, recognized the Carboniferous type of its fauna, when he first introduced the term (report for 1860). He made a heavy sandstone which he called the Napoleon the base of the Carboniferous, and called the

[1] Compare Schuchert, Pls. 78 and 79.

beds beneath the Marshall, the top of the Devonian corresponding to Chemung. Later[1] his investigations led him to include this Marshall with the Carboniferous, and then he also united the Napoleon andstone with it as Upper Marshall, and finally concluded apparently that it was not worth separating but only a lentil. The whole matter is discussed in full in the Huron County report. The Marshall is evidently a case of emergence on the east first, micaceous sandstones becoming more and more abundant, and bands of carbonate of iron and fossils, while blue shales still persist in layers. At a number of places white sandstones occur and thin beds of what I have called peanut conglomerate, white quartz pebbles with heavy cement of carbonate largely of iron, which weathers brown and gives the color effect of peanut candy. The transition from Coldwater is gradual, and it is not easy to fix the line consistently. In fact there are some paleontological reasons for believing that the whole southwestern Marshall may be older than the Huron County.

The Huron County section is fullest, as follows:

Napoleon (Upper Marshall) sandstone	300	300
Lower Marshall (Original Marshall)		
Hardwood Point shales and sandy flags, fossiliferous, "typical Marshall" fauna	85	385
Point Austin sandstone	23	408
Sandy shale	68	476
Point Aux Barques sandstone	18	494
Shales and flags with Romingerines Julia	41	535
Grindstones with bands of peanut conglomerate and broken goniatite shells	25	560

The southern Marshall is thinner and since it is an emergent formation it is easy to assume that this part of the formation emerged sooner and was more eroded, and not so soon covered. The series that came after the emergence should also be less complete and as a matter of fact the Michigan series here lacks gypsum and seems otherwise less complete.

But may it not be that not only did emergence but the tendency toward emergence indicated by the sandy facies begin sooner? There is faunal indication of this.

[1] See references in Weeks, *Bull. 191, U.S.G.S.*, 260. But add also *Am. Jour. Sci.*, XXXIII, 352–56, and *Proc. Acad. Nat. Sci.*, XIV, 405–30.

A simple and natural explanation of faunal relations would be that the Marshall emergence took place earlier to the southwest than to the northeast. This does not agree with Schuchert's maps. If so, the question at once arises, must we not reverse our definition of the Lower Marshall, bringing it down to include the Raccoon shales and their equivalent in Huron County, down to Port Hope nearly, adding 200 feet to the Huron County section, and making the Marshall there over 760 feet thick? This may be the future solution of the question. Cooper leans to it. But we should be as sure as possible before making changes. So we must ask what indications are there of a land mass in this direction? Also are there any indications of a shortened geological column to the top of the Marshall in this direction?

There is a little thinning as compared with the Huron County section, but not enough, and no shrinkage as compared with the center of the basin. We have besides to allow for a dropping-out of Berea beds and for the unusual thickness of the Huron County Upper Marshall as given in the column which seems *very* local.

The limestone character of the western Coldwater is rather against its earlier emergence, as well as the relatively wide spread of the western Kinderhook.

There is an alternative hypothesis (supposing the paleontological facts to remain established) and that is to suppose that the Paleoneilo fauna of the Raccoon shales were immigrants northward that reached Ohio earlier but did not reach Michigan until later—until after the beginning of the Marshall. This seems to me the more likely because the fauna most like that of the southern Michigan Marshall that we find in Huron County is way up in the Lower Marshall at Flat Rock Point.

31. *Michigan series, Lower Grand Rapids.* Logan possibly absent in Ohio? (380—generally about 200).—The Marshall is Kinderhook of the Illinois reports. Following the Marshall there was an emergence and an interval of erosion without deposition of some time around the edges of the basin, but perhaps none near the center, for the series there is of greater thickness and its deposits of gypsum attest its cut-off character. In the Mount Pleasant well it is 358 feet

thick—the fullest of any in the state. There is always a gypsum or anhydrite bed near the middle of the formation, and with this is associated dark-colored dolomites and dark-blue shales. Sandstones are thin and irregular and in some cases there are dark limestones toward the base. These dark, impure limestones, are quite different from the Bayport limestone. The section around the margin if at all full is something like 200 feet, but from Tuscola County south to the Assyria are a lot of wells in which it is hard to recognize this or the Bayport at all. Occasionally, as around Byron, very salt water near the surface may indicate outliers of it. The water from the formation is salty and "bitter," full of calcium and magnesium sulphate and in that respect very different from the Marshall immediately underlying. The absence of the Michigan series from the southeastern part of the state seems to be due not wholly to erosion at top, but to uplift of the bottom, the emergence of the Marshall having progressed so far that this part of the state like the corresponding part of Ohio was out of water.

The date of this emergence during which the Lower Michigan was forming in the center of the basin is pretty definitely fixed on paleogeographic grounds as that of the Upper Augusts or Osage.[1] The Michigan series seems to have continued forming until a depression to the west opened connection with the wide ocean at the time of the Maxville of Ohio, Upper St. Louis or Kaskaskia and Chester of the Mississippi Valley. The section seems to be continuous without disconformity to the overlying limestone, which I have called Upper Grand Rapids, since both sets of beds were well exposed near Grand Rapids and seem in many ways bound together. The Lower Grand Rapids must then include the Lower St. Louis and probably the Keokuk and perhaps in the center strata representing part of the Burlington, the time Kinderhook-St. Louis including an era of emergency in which all of Michigan but a central sea was out of water.

The dark and sometimes even black slates and the blue and dark, impure dolomites give the formation a more muddy look than the Salina, while the general association of dolomite and gypsum is like that of the Salina, and one is inclined to believe that some land waste and rain erosion were still going on, though local conditions favored

[1] The emergence between Schuchert's Mississippi and Tennessee.

concentration and after all chemical erosion and deposit were much more important in the Grand Rapids than at any time since the Traverse.

32. *Maxville or Bayport limestone, Upper Grand Rapids, Upper St. Louis, Middle Kaskaskia.* (50 to 235 feet usually eroded).—This formation marks the culmination of a transgression.[1] Generally it is only 50 to 75 feet thick or less, and seems to be much eroded away by a heavy erosion and uplift that took place after its formation. But in the Mount Pleasant well 235 feet may belong here.

Light, hard limestones, bluish with chert and white sandstones are characteristic. It is the typical old subcarboniferous limestone. Faunally (with Allorisma, Lithostrotion canadense, etc.) it is also closely allied with the Upper St. Louis, the middle of the Kaskaskia, and the Ohio Maxville—an epoch of maximum ocean extent at this time. I do not know any good reason for not calling it Maxville.[2] Owing to the heavy subsequent erosion there is no telling how far it may have extended, but it certainly extended into Huron and Arenac counties and thence west. It also extended south of Jackson, and may once have gone into Ohio continuously.

However, in a region from Tuscola County south around Durand, Morrice, and Howell, there seems to be an area where it does not now occur and perhaps never occurred. An anticlinal uplift either prevented its formation or caused it to be eroded away. From Jackson to Grand Rapids past Bellevue and Assyria, however, there are frequent signs of its presence though the coal measures are laid upon it with a very marked unconformity.

On the whole, the climate was not one that favored the formation of shales, but limestone, chert, and clean white sandstone rather, and as the continent was sinking the rivers tended to aggrade and leave their mud before reaching the sea.

At the close of the Bayport formation the state was quite likely lifted entirely above water for quite a while,[3] since wells in the center of the basin as near to each other as Alma, Mt. Pleasant, and Midland show very different sections, and the Parma conglomerate base of

[1] Schuchert's Tennessee which he makes early Chester, Pl. 81.

[2] See *Michigan Miner*, December, 1906; *U.S.G.S. Water-Supply Papers*, 182 83.

[3] Schuchert, Pl. 82.

the coal measures appears sometimes at one level, sometimes at another. The Bayport is apparently entirely gone at Alma.

This, then, would be the line between the Mississippian and Pennsylvanian, in this state the strongest disconformity since that at the base of the Devonian, and the first time that there is any evidence that the whole of the state was above water.

PENNSYLVANIAN

33. *Parma conglomerate; Pottsville* (170 feet; basal member).—The recurrence of deposits in Michigan is marked by a bed of conglomerate. The pebbles are not always present, to be sure and are rather small and very white, about like split peas, and the mass of the formation is sandstone. The name is taken from a point on the margin of the basin which is very likely contemporary with shales, etc., in the center. As a term, then, it is, like the Potsdam, not to be taken as of definite age but as the underlying basemental and shoreward facies of the Saginaw formation. As a very persistent horizon easily recognized by the presence of pebbles, which are rare in the Michigan column, and as an economically important water bearer it deserves a place in the column. Compared with the Marshall brine beneath, it has less of the earthy chlorides, more of the sulphates.

The wells of the Saginaw Plate Glass Works yielded a set of samples which show the characteristic Parma and the strata above and below.

34. *Saginaw formation. Upper Pottsville* (400).—This is the coal-bearing series of Michigan. All the other formations seem actually to dip and occur deeper at the center than at the margin of the basin. Mr. Barnes, chief driller of the Consolidated Coal Co., thinks that for this, too, the marginal coal seams, at Sebewaing and Jackson, correspond to the deepest seam at the middle. I am hardly inclined to think it. Their chemical character is more like upper seams and the fauna and flora of the upper seams at the center and at the margin seem similar.* The series is a succession of white shales (so-called fire clays) or sandstones, black shales (called slate) and coal, and blue shales, with occasional thin bands of black band ore (siderite), and nodules of the same containing zinc blende and iron

pyrites, and very rarely limestones with marine fossils.[1] More commonly, but still rarely, in the black shales a *Lingula carbonaria* or *mytiloides*, and at Grand Ledge a little pelecypod like Anthracosia occurs, and this Lingula seems to mark a definite horizon, that of the Upper Verne, the two Verne coals often occurring close together and sometimes having a limestone between.

The fauna and flora indicate Upper Pottsville (Beaver or Kanawha) near Mercer (compare the Kanawha, Black Flint, Mercer limestone and Stockton coal), and is also near the top of the Saginaw formation. How much lower the base may possibly go we have no means of knowing. But there is reason to believe that there was not continuous deposition even in the center of the basin, and the Upper Pottsville is over 1,200 feet in West Virginia.

As a whole, the formation is composed of beds of rather rapidly varying thickness and character. This is true also of the coal seams. In one mine they will rise and fall 20 feet and more, pinch out or pass into black shale. A curious feature is a local persistence of facies. That is, in one township there will be a great deal of sandstone at many levels, at another there will be much shale at all levels, in one region many of the coals will be prominent, in another none. Finding a good upper coal is by no means a sign that the coals below will be extra thin.

This points to a certain persistence of geographic condition. That is, if a big sand dune or sand bar occurred in a point flanked by a peat swamp on one side and muddy clay-depositing waters on the other, while it extended more or less widely and shifted a little from time to time, yet it tended to remain in the same general region and even built up as the general level of the water rose. We can see that this might be so by watching the effect of rises and falls in the level of the Great Lakes. A rise of 7 feet may not seriously shift the location of a swamp and the barrier beach that cuts it off from the main lake.

The writer made a list of some seven coal horizons, to which Cooper has added seven more. When we consider that the whole 14 occur within 400 feet, most of them too thin to work, and that one seam may vary 20 feet or so in elevation in a couple of hundred feet,

[1] Vol. III, Part 2, 42, 43, 96, 203; *Report* for 1907, 19; *Report* for 1905, 185, 188.

but little stress can be laid on any such series. The Verne bunch are, however, at a fossiliferous (Mercer) horizon often quite close together, showing as a 7- to 8-foot wall with partings (compare the Stockton coal) and it is curious that White gives 13 horizons in the West Virginia Upper Pottsville.

I have an idea that they give a drowned-river-valley effect to the southeast side of the basin, the longest axes of the coal running northwesterly in a very irregular way, but the general shore-line trending southwesterly from Huron County, something like the Carolina shore south of Hatteras turned around.

POSSIBLY PERMO-CARBONIFEROUS?

35. *Woodville sandstone.* 110 feet (Conemaugh).—Winchell separated off above the coal measures a sandstone 79 feet thick he called the Woodville. It was named from an exposure at Woodville near Jackson.

Now, at Maple Rapids, St. Johns, Ionia, and Gladwin,[1] we find a brown or reddish sandstone. This is not a normal color for a coal-measure sandstone. It may be that this reddening is an effect of weather, but I think not, and we may as well call it Woodville until we know the Woodville does not represent it. Ionia would be a much better name. The Woodville exposure is not red but buff. Still it is weathered, friable, and over 40 feet thick. From the way these red beds occur in some wells but not in others near by in the Saginaw Valley we may be pretty sure that they are unconformable to the series below. I suspect, therefore, that it is not Allegheny but at earliest Conemaugh, some land-formed deposit of the late Carboniferous (Pennsylvanian) or early Permian. No fossils are known. The red formations seem to be more abundant in the western part of the state but that part is heavily covered with drift, and the redness may be a purely secondary Mesozoic oxidation.

During the rest of the Paleozoic,[2] the Mesozoic and the Tertiary Michigan was, so far as known, out of water, though there is reason to believe that at the time of the Cretaceous the sea reached nearly or quite to it, and it was nearly worn down to base level. At some time everything from Niagara to Keweenawan around Lake Superior was

[1] Vol. III, Part 2, 158, 159, 164, 166, 195, 196, 197.

[2] Schuchert, Pl. 84.

leveled off, and even the harder felsites and granites did not rise more than four or five hundred feet above the general level. As we find fragments of Upper Cretaceous not far off in Minnesota on the Mesabi Range we are inclined to put the culmination of this period of leveling at that time.[1]

On the other hand, deeply incised valleys and caves in limestones suggest a period of high level in the Tertiary between that time and the ice age. Some time someone may find in the prosecution of the limestone quarrying, around Fiborn or Alpena or Monroe in the caves upon which one comes, vestiges of Tertiary cave life. I do not know of any yet.

PLEISTOCENE AND RECENT DEPOSITS. 1,110–0 FEET

Michigan is so near the center of the latest glaciation and that was geologically so recent, the effects of ice blocking the St. Lawrence valley having lingered so far as one can judge until within a few thousand years, that it does not seem sensible to divide the Glacial and Pleistocene from the present. Mammoth and mastodon bones are found within a few inches of the surface and where forest clad, the topographic forms left by the ice are almost as sharp as when left, with much less alteration than 50 years of farming make. However, beds of peat 30 or 40 feet thick, of boglime, lacustrine, and alluvial clays 14 feet thick and perhaps more have accumulated and formations like the delta of the St. Clair flats, Tawas Point. So far as we can estimate none of these post-Glacial deposits need have taken over 10,000 years.

The greatest thickness of the Glacial-Pleistocene deposits we may estimate to be 1,110 feet near the north line of Osceola County, southeast of Cadillac. But the greatest thickness actually measured is in the deep wells near by on the Lake Michigan shore at Manistee and Ludington, where the rock surface is below sea-level, but they can hardly be separated systematically in a geological column. Both in the character of the pebbles, however, and in other ways, a transportation from the northwest as well as the northeast is plainly indicated, and at least one period between the two during which red lake clays were in some places laid down.[2]

[1] Schuchert, Pls. 94–95.

[2] *Report* for 1906, Russell on "Surface Geology," 43, 73; Rominger, I, Part III, 17.

CRETACEOUS–EOCENE CONTACT

TOMBIGBEE RIVER, ALABAMA

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The Selma chalk, which is so beautifully exposed at Demopolis on the Tombigbee River, grades upward into a more argillaceous material a few miles below the town. A fine exposure of this variety is at Barton's Bluff on the left bank of the river, about ten miles below Demopolis. For a distance of a mile or two above Barton's and at the bluff itself, there are scores of faults of a few feet displacement. Some of these are of the nature of step faults, others, especially as the bluff is neared, bring the white chalk of the Demopolis variety in wedge-shaped blocks up into the dark-colored clayey material characteristic of the bluff as a whole. In places the strata show a very considerable amount of flexure in addition to the faulting. Fig. 1 is given in illustration.

Below Barton's for some distance the banks of the river show very few good sections until Moscow Landing is reached. Here the bent, fractured, and faulted beds of the Cretaceous are overlain unconformably by the lowermost (Midway) beds of the Eocene of this section.

The main mass of the Cretaceous, forming the base of the section exposed at Moscow, is a light-colored argillaceous limestone not unlike the Selma chalk of the Demopolis type. The dark-colored clayey beds of Barton's Bluff are not shown here. This limestone is a somewhat massive rock with stratification lines very obscure, but near the top of the formation there is a thin layer of phosphatized shell casts which may easily be followed along the bluff and by which the attitude of the strata may clearly be made out. The Eocene beds which form the upper fifteen or twenty feet of this section are of material very similar to the Cretaceous limestone below. Along a good part of the bluff this Eocene limestone lies in immediate contact with the Cretaceous, and when this is the case the uncon-

formity is very little apparent, since the phosphatized shell-cast layer of the Cretaceous, above alluded to, runs practically parallel to the stratification lines of the Midway with a gently undulating dip down stream. Near the base of the Eocene there is a thin layer of shells of a small oyster (*O. pulaskensis*, Harris) which very clearly indicates the attitude of the Eocene strata, as the layer of phosphatized shell casts does that of the Cretaceous. At the extreme right and left of Fig. 2, this approximate conformity is shown. The dark line immediately above the contact is made by the layer of oyster shells.

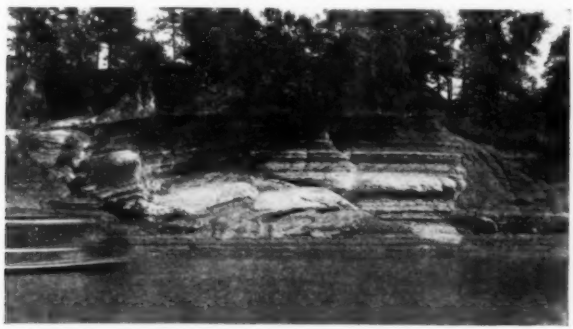


FIG. 1.—Flexures and faults in Cretaceous strata at Barton's Bluff, Tombigbee River, ten miles below Demopolis, Ala.

At intervals, however, especially in the up-stream part of the bluff, there are hollows in the Cretaceous limestone, formed partly by erosion and partly by flexure, in which are plano-convex lens-shaped masses, twenty to forty feet in length, made up (*a*) of a sort of conglomerate of Cretaceous shells, mainly exogyras and gryphœas, in a chalky argillaceous limestone matrix, in all some three or four feet in thickness, and above this, (*b*) a glauconitic sandstone, strongly crossbedded and filled with Cretaceous shells, some of them very much water-worn. These two fillings may clearly be seen in the lens at the left of Fig. 2. In the lens at the right of the figure the sandstone is very prominent, but the underlying shell conglomerate does not show so well. A remarkable thing about these sandstone lenses is the manner in which the strata are flexed and their edges

FIG. 2.—Moscow Landing, Tombigbee River, Ala. Contact of Cretaceous and Eocene, the latter resting directly on the beveled edges of the sandstone lenses, and where these are not present, upon the Cretaceous limestone, often in apparent conformity. Immediately above the line of Cretaceous-Eocene contact another line may be traced the whole length of the bluff, made by a thin layer of the shells of *Ostrea Pulaskensis*. The central part of this section is much disturbed by faulting which involves both Cretaceous and Eocene. Three sandstone lenses are here seen occupying erosion or plication hollows in the Cretaceous limestone.

beveled off at the contact with the Eocene. This is particularly well shown in the lens at the right of Fig. 2.

Overlying the Eocene limestone, lower down the river than either of the views shown in the figures, are black shaly clays, the Sucarnochee clays of the Alabama Survey, exposed in great thickness at Black Bluff a few miles below Moscow Landing.

Near the upper end of the Moscow Bluff both Cretaceous and Eocene beds are faulted, the displacement being generally only a

FIG. 3.—Bluff near Moscow Landing, Tombigbee River, Ala., showing two of the sandstone lenses in erosion hollows in Cretaceous limestone. Both Cretaceous and Eocene strata are faulted. The strata which directly overlie the beveled edges of the sandstone lenses are Eocene.

few feet, as may be seen in Fig. 3, the beds immediately above the beveled-off sandstone lenses being Eocene. Along many of these fault planes sheets of calcite, one or two inches in thickness, have developed, with one surface after the manner of a slickenside.

When this bluff was first visited by D. W. Langdon and the writer in 1886, the small oyster was thought to be *O. vomer*, and the whole section, with the exception of the black clays at the lower end of the bluff, was referred to the Cretaceous; but on a visit to the locality

made in 1908 by a party of state geologists and others on a trip down the river from Tuscaloosa to Jackson in Clarke County, several specimens of *Enclimatoceras Ulrichi* were found in the upper limestone bed, and the small oyster was recognized as *O. Pulaskensis*, thus establishing the horizon as that of the Midway.

It has been suggested that the glauconitic sandstone is a basal Eocene bed, but its local character and the unconformity between it and the Midway everywhere would militate against this view. The unconformity, in places, between it and the Cretaceous below, is, however, equally pronounced.

There are many things about these sandstone lenses which are not easily understood. Thus, to all appearance these beds after their deposition have been tilted and their edges beveled by erosion, and this in one or two cases without any perceptible disturbance of the Cretaceous limestone upon which they rest. This is shown by the fact that the bed of phosphatic shell casts, which presumably marks a stratification plane in this limestone, in approximately horizontal position, in some cases, maintains this attitude to the very edge of the erosion hollow containing the shell conglomerate and sandstone; while in other cases this phosphatic shell bed bends down below these hollows, as though they were produced by plication and as though the stratification of the Cretaceous limestone were conformable to that of the shell conglomerate and sandstone.

THE INFLUENCE OF THE EARTH'S ROTATION UPON THE LATERAL EROSION OF STREAMS[1]

HENRY M. EAKIN

Introduction

It is a well-known fact that rotation of the earth upon its axis sets up a tendency in bodies in motion upon its surface to deviate from a straight course, in the northern hemisphere to the right, and in the southern, to the left. Different writers[2] have considered the possible results of this tendency in modifying stream erosion, but in general little importance has been attached to it, striking results of its operation not being commonly observed.

The most satisfactory analysis of the problem is Gilbert's, in which he notes certain processes involved in stream erosion not usually considered and endeavors to make a quantitative measurement of the effect of the deflective force acting relative to them. He points out that centrifugal force is developed on the curves of meandering streams. Velocity being a factor of this force, so-called "threads" of higher velocity will tend more strongly toward the outer bank on curves. The rotational deflective force depending also upon velocity will affect the "threads" of higher velocity more strongly. The effect of this stronger tendency of the swifter threads one way or the other he expresses as a "selective influence," whereby they migrate nearer one bank or the other, displacing threads of lower velocity and accelerating lateral erosion. In the northern hemisphere the rotational deflective force acts in conjunction with centrifugal force on right curves, and on left curves in opposition to it. Consequently the locus of maximum velocity would be shifted toward the outer bank more strongly on right curves than on left curves, the cross-

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] Dunker, *Zeitsch. für die gesammten Naturwissenschaften* (1875), 463; Klockmann, *Jahrb. Preuss. Geol. Landesamt* (1882); Geikie, *Textbook of Geol.*, I, 23; Chamberlin and Salisbury, *Geology*, I, 184; Jefferson, *Bull. Geol. Soc. Am.*, XVII, 333–50; Gilbert, *Am. Jour. Sci.*, 3d ser., XXVII, 427.

section profiles of the stream would be correspondingly modified, and a difference in lateral erosion would ensue. The efficiency of rotation to produce appreciable results is advocated only in "connection with and as an adjunct to lateral wear by means of curvature."

In certain Alaska streams the writer has noted a strong predominance of erosion on the right bank, shown by asymmetry in the position of the river with respect to the flood plain, the distribution of bluffs on the right and left limits, and in the distribution of bars and islands relative to cut banks. In the case of the Yukon, in the last 600 miles of its course the flood plain, 20 to 50 miles wide, is almost entirely on the left-hand side. It flows close to the right valley wall almost the entire distance, often with steep, fresh-cut bluffs in bed-rock. The left bank is commonly alluvium, bed-rock being encountered only once in this distance. And in the single instance mentioned, opposite the mouth of the Melozi River, a large delta has been built out by the tributary stream, literally crowding the larger river over to the left valley wall. In this part the Yukon is essentially without meanders, being characterized by long straight reaches and gentle curves.

Also of great significance in the case of the Yukon is the behavior of driftwood and floating débris. Such material is almost entirely absent from the left bank, but is plentiful on the right. And in flood time, when the current is well supplied with such material, its distribution on the stream surface is most striking. It is confined almost entirely to the right half, and often to a much smaller space along the right bank. Eddies along the right limit are often crowded with drift; along the left never, so far as observed. At Nulato, where the river is about a mile wide, the natives get a large supply of wood by catching drift logs, and they seldom have to go more than 300 feet from the right bank to secure them.

The problems presented by these conditions have stimulated study, which has led to an analysis of the processes of river erosion considerably different from that described above. In the following pages, after a simple review of the principles to which the deflective force is due, it is intended to emphasize its greater strength in higher latitudes, to show that its expression in unbalanced lateral erosion is least in streams where meanders are in process of development and

greatest in streams with straight courses—that the force is opposed to the development of meanders and in high latitudes may fully account for the conditions described above.

The Deflecting Force of the Earth's Rotation

For a brief elementary review of the principles which give rise to this deflecting force, we may imagine the earth perfectly smooth and friction eliminated. This force has two modes of origin, one being active when the relative motion is in an east-and-west direction, the other when the relative motion is north and south. In case the relative motion is not in any true direction, both modes are active at once, and the deflecting force has two components arising in different ways, but acting similarly.

To get these components distinctly in mind we may consider them separately. (For convenience the following abbreviations may be used: F_g=force of gravity, F_c=centrifugal force, F_d=deflective force of the earth's rotation.)

Component of Deflecting Force Arising from East-and-West Relative Motion

An object upon the earth's surface and at rest with respect to it has a certain gyratory velocity equal to that of the earth's surface at the same latitude. This gyratory motion gives rise to a centrifugal force, acting in a plane normal to the axis of rotation. Owing to the nature of the ellipticity of the earth, a gradient is furnished at every point whereby a part of the force of gravity is caused to oppose and exactly counterbalance this centrifugal force, and the object would have no tendency to move either toward or away from the equator.

However, if the object had an easterly motion with respect to the earth's surface, it is readily seen that the centrifugal force would be increased and the ellipticity of the earth's surface would no longer be sufficient to cause its counteraction by gravity. The resultant force would furnish a component acting along the earth's surface toward the equator to the right in the northern hemisphere and to the left in the southern. Again, if the object had a westerly motion relative to the earth's surface, the centrifugal force would be decreased

and the ellipticity of the earth, being more than a match for it, the object would tend to slide down the gradient toward the poles, to the right in the northern hemisphere, with respect to the direction of its relative motion, and in the southern hemisphere to the left. These principles do not require that the object move directly east or west, but operate so long as there is an easterly or westerly component in its relative motion.

Component of F_d Arising from North-and-South Relative Motion

Another component of the deflecting force of the earth's rotation arises when the relative motion is in a northerly or southerly direction. Suppose an object at rest with respect to the earth's surface at a latitude of parallel A be acted upon by a force causing it to move to a higher latitude of parallel B. At parallel A the object had a certain gyratory velocity corresponding with a point in the circle A. Being drawn toward the center of gyration in moving to a smaller circle, this gyratory velocity is accelerated according to the law of conservation of angular momentum. And since the gyratory velocity of a point in Circle B is less than that of a point in Circle A, and the gyratory velocity of the object is greater than that of a point in Circle A, the object has come to have a gyratory velocity very different from the earth's surface at the same latitude.

This difference would give the object a relative motion in an easterly direction, to the right in the northern hemisphere and in the southern hemisphere to the left.

If the object were at rest at Circle B and were caused to move to Circle A, the reverse of the above case would be true. The actual gyratory velocity of the object would be decreased according to the same law, and the earth's surface would have a higher velocity at Circle A than at Circle B. The object would have gained a negative component of velocity in a westerly direction with respect to the earth's surface, and, as before, the deviation would be to the right in the northern hemisphere and to the left in the southern. In either case should the object have, at the start, a relative motion, the same principles would be effective.

Effect of F_d on Objects Moving in Fixed Courses

Obviously, if the object were not free to move as these forces would direct it, but were constrained to move in a fixed channel, the deflecting force would cause it to press against the side of the channel. Now, if the channel were along a meridian, only one component of the deflecting force would be active, or, if along a parallel, the other alone. But if the channel were in any other direction, the movement of the object would have both a north-and-south and an east-and-west component of motion, and both components of the deflecting force would operate proportionately to the components of relative motion from which they arise. And since, according to Ferrel,[1] the amount of the deflecting force arising from an east-and-west relative motion is exactly equal to the amount due to a north-and-south relative motion under similar conditions, it follows that at any given latitude for the same rate of relative motion, the deflecting force is constant, regardless of the direction of the relative motion.

Measurement of F_d

The amount of this deflecting force varies with the rate of relative motion and the latitude.

Using Ferrel's formula,[2] $\frac{F_d}{g_m}=\frac{2NS \sin L}{9.806}$ (N=gyratory velocity of the earth in terms of the radius; S=rate of relative motion; sin L=sin. of the angle of lat.; g=accelerative force of gravity), and adopting arbitrarily a definite rate of relative motion of 2 meters per second, or $4\frac{1}{2}$ miles per hour, the expression of the deflecting force in terms of the force of gravity for each fifth degree of latitude is given in column 2 of Table I.

Taking the amount of the deflecting force at the fifth degree of latitude as a unit of measurement, the amount active at each fifth degree of latitude is given in round numbers in the third column of Table I.

For comparison with the more familiar effect of F_c as developed on curves, radii of curvature have been computed which would

[1] Ferrel, *Popular Treatise on the Winds*, 42–88.

[2] Ferrel, *loc. cit.*

generate F_c, approximately equivalent in effectiveness to the deflective force operative under the same conditions at each fifth degree of latitude. These figures are given in column 4, Table I. The same velocity is assumed as in the former calculations. (In these computations a symmetrical arrangement of velocities with respect

TABLE I

Lat.	$\frac{F_d}{F_g}$	Ratio	R
5.....	.00000260	1	65.00
10.....	.00000516	1.9	33.0
15.....	.00000770	2.9	22.0
20.....	.00001018	3.9	16.0
25.....	.00001258	4.8	13.0
30.....	.00001488	5.7	11.0
35.....	.00001706	6.5	10.0
40.....	.00001912	7.3	8.6
45.....	.00002104	8.0	8.0
50.....	.00002278	8.7	7.3
55.....	.00002438	9.3	6.8
60.....	.00002576	9.9	6.5
65.....	.00002696	10.3	6.2
70.....	.00002796	10.7	6.0
75.....	.00002874	11.0	5.8
80.....	.00002930	11.2	5.7
85.....	.00002962	11.3	5.66
90.....	.00002974	11.4	5.60

to a central maximum, decreasing directly with the distance from the center to zero at the margins, has been assumed. This introduces an error which gives a greater relative value to F_c and adds to the value of the radii computed. This error varies with the actual arrangement of velocities in the stream, but probably would never amount to more than a small percentage.)

Rôle of F_d among the Forces of Flow

In studying the movements of water in a normal river we have to do with three forces that are setting up and directing currents: F_g acting down the general stream gradient, causing the primary current, and F_c and F_d arising from this primary movement and acting always at right angles to the direction of flow, F_c always toward the outer bank on curves and F_d always to the right in the northern hemisphere, to which the study will be confined in the following pages.

Each particle in motion feeling a lateral impulse, whether from F_c or F_d, will tend to move in that direction. For simplicity, we may take the case of a stream acted upon by F_d only. The lateral impulse will be transmitted to the right, so that each particle will feel the combined impulse of all those to the left in strata of equal pressure. The tendency will be for all to move to the right until a lateral gradient is established that will furnish at each point an equal impulse in the opposite direction. In a stream with velocities in each stratum of equal pressure arranged symmetrically with respect to the center, this gradient would be a compound curve with a general inclination to the left (see *aa*, Fig. 1).

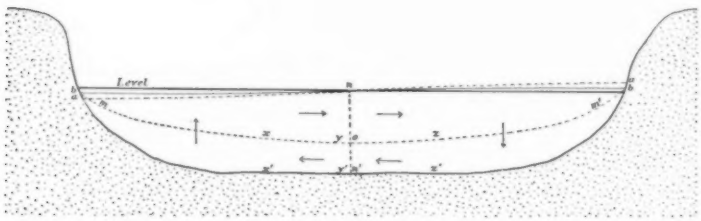


FIG. 1

But this potential gradient is never established. The velocities of the particles at x', y', z' (Fig. 1), being less than those at x, y, z, are unable to support the same lateral gradient, so that, before the potential lateral gradient for x, y, z, is established, some lesser gradient will cause a movement of x', y', z' to the left. This actual gradient would be constant for any set of conditions and would also be a compound curve (see *bb*, Fig. 1).

At some point between x and x', the force of F_d will just equal the opposing impulse from the actual lateral gradient. At this point no lateral movement will take place. Above it movement to the right will occur, below it, movement to the left. Between other points similarly related, like conditions will hold, giving a zone in which lateral movement is absent (*mm'*, Fig. 1).

Since the curve representing the potential gradient is stronger than that of the actual and the area of the cross-section of the stream

is practically constant, at some point the two must coincide, and no vertical movement will occur. And so, for each stratum of equal pressure we will have a zone (nn', Fig. 1) without vertical movement. To the right all particles will have a downward component of motion, to the left, an upward component. At the point of intersection of mm' and nn' all impulses are balanced save F_g acting down the stream gradient.

The stream has, then, a central axis about which a sort of revolution takes place. Under the influence of either F_c or F_d or of both, the stream progresses with a boring movement.

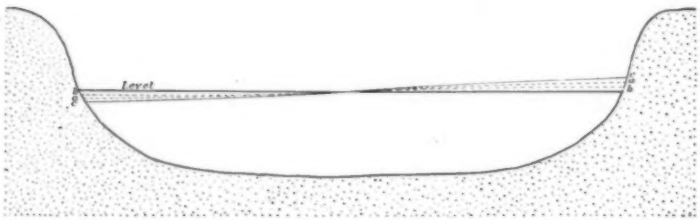


FIG. 2

Being the last factor that can be closely approximated, we may take the potential lateral gradient of the stratum of maximum velocities on the right and left curves of a meandering stream as a measure of the relative tendency of lateral erosion.

On the right curves F_c and F_d will combine. This condition is expressed graphically in Fig. 2, in which aa' represents the gradient arising from F_c, bb', that from F_d, and cc', the resultant.

The condition of left curves is illustrated in Fig. 3, aa' representing the potential gradient due to F_c, bb', the potential gradient due to F_d with the inclination to the right, and cc', the resultant potential gradient, being the mean.

Mathematically the potential lateral gradients on right and left curves may be computed and compared.

Using Ferrel's formulae for F_c and F_d and the data of Humphreys and Abbot on the Mississippi at Columbus, Ky., the potential lateral gradient would be 18 per cent stronger on the right curves. In this

case, however, the velocity data are taken from measurements on a straight reach of the river having a very symmetrical profile. The distribution of velocities being very different on curves, different relations would probably hold between the mean velocity and mean squared velocity, and the above ratio would be changed. The computation, the result of which is given above, involves less assumption than any other method of attacking the problem discovered and the figure, 18 per cent, may be safely considered of the same order of magnitude as that expressing the actual difference of potential lateral gradients on right-and-left curves in this case. The relation

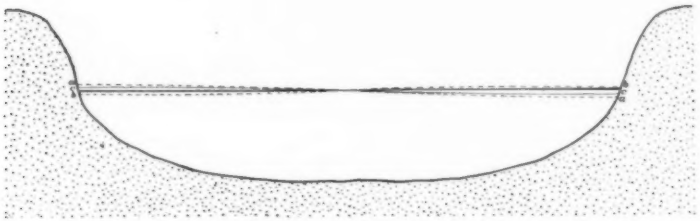


FIG. 3

between potential lateral gradient and consequent lateral erosion varies with other factors so that an attempt to compare the actual erosion on right-and-left curves would be idle. It is readily seen that, as the radius of curvature increases, the relative value of F_c decreases, until on straight reaches it becomes zero. On straight reaches, then, F_d is acting alone, and the tendency is 100 per cent to the right, its strength depending on the velocity of the stream and the latitude.

BORING CURRENTS IN A MEANDERING STREAM

In a meandering stream the potential lateral gradient is reversed on each successive bend. The tendency is for all particles in motion to move toward the outer bank, establishing an actual lateral gradient corresponding to the potential. For a period, friction being low, the actual gradient will be high, since the momentum of the boring currents developed on the preceding curve must be checked and lateral inertia overcome before the boring currents normal to the

reversed gradient gain headway. But as such lateral currents are accelerated, friction increases. Friction in that part of the current moving in a positive direction or with the lateral force consumes part of the energy of the lateral impulse so that the actual gradient is lowered. Friction in the part of the current moving in the negative direction consumes part of the accelerative force of the actual gradient.

A condition of equilibrium is reached when the actual gradient becomes such that it is just maintained by the excess of lateral impulse over friction in the positive part of the current and whose accelerative force is balanced by friction in the negative part of the current. This adjustment is made by the shifting of the stratum of non-lateral movement which alters the relative proportions of the positive and negative parts of the current. The higher the actual gradient the larger will be the negative part of the current. As acceleration goes on and the actual gradient becomes less, that part of the current having a negative component of motion becomes more and more closely confined to the bottom of the channel and its efficiency in handling débris correspondingly increased. The condition of equilibrium would represent the maximum of efficiency. That such a condition is not represented in much of the course of a meandering stream is sure. That it is represented in any part is not certain.

Boring Currents in a Straight Stream

On straight reaches no reversal occurs. The condition of equilibrium between lateral forces and friction should be established. Therefore F_d, operating on straight reaches, should be immensely more effective in directing lateral erosion than an equivalent amount of lateral force operating in a meandering stream.

As pointed out by Hagen,[1] Herschel,[2] and others, the power of flowing water to erode its channel depends very largely upon the swirls, eddies, and such inner movements of particles among themselves. Such minor movements might well be called the teeth of the current, it being for the most part their action that wrests material from the bank or the bed of the stream and places it in proper relation to the current to be transported. These minor movements are due to friction between parts of the current, differing in velocity. Their

[1] Hagen, *Handbuch der Wasserbaukunst*, Part II, Art. 21.

[2] Herschel, *Jour. Franklin Inst.*, 3d ser., LXXV, 401.

strength and effectiveness depend upon the amount of difference in velocity in a given distance.

The lateral shifting of the locus of maximum velocity and the downward deflection of the stronger upper currents adjacent to the outer bank on curves mark these points as loci of maximum erosion. But equally important in the development of meanders is the deposition of the débris resulting from the cut, normally on the inside of the next curve below the cut, and on the same side. Early in the development of a meander the lateral currents are weak. The débris-laden currents are not shifted far toward the center of the stream before the reversal occurs, their carrying power is changed, and deposition takes place. In more developed meanders the lateral currents being stronger, the loaded parts of the currents are shifted farther and carry their burden a greater distance. In development of meanders, then, the débris is deposited farther and farther from its source, but normally on the same side. When the meanders are strongly enough developed, the load should be shifted entirely across the channel and back again on subsequent curves, and in this may lie an important factor in controlling the width of meander belts.

If, however, in the case of a stream having a straight course, currents are set up by a force other than that due to curvature, the débris will be shifted constantly in the same direction. There will be no deposition below the cut on the same side, and consequently no deflection of the stream. The lateral currents, being constantly in one direction, will mark one side of the stream for dominant cut, and the other for maximum fill.

Whether due to F_c or F_d, the selective cut and fill due to the lateral currents introduce and maintain an asymmetry in the channel profile which, in turn, further modifies the distribution of mass and consequently of velocities in the stream cross-section. The result is to accentuate the selective cut and fill due directly to the lateral currents. The slightly increased depth on the side of the stream toward which the lateral force acts furnishes still another, though probably small, factor in favor of the same selective erosion.

If the foregoing principles are true, we have an adequate explanation of the peculiarities shown by the Yukon and other Alaska streams.

The Tanana River, the largest tributary of the Yukon, in the last 200 miles cuts bed-rock only on the right side and has almost all of its extensive flood plain on the left side. The lower Koyukuk has broad flats to the left and usually rock-cut banks on the right. Spurr notes a similar condition in the Kuskokwim, and Maddren in the Innoko. Though lacking the absolute data on which to base definite measurements of the effect of rotational deflection, the general knowledge of the streams mentioned above seems sufficient to establish the fact of its notable operation in high latitudes. That other causes may produce asymmetrical valleys is not denied. If a larger amount of rock débris is supplied by the tributaries on one side than on the other, the tendency is certainly to crowd the main stream to the opposite valley wall. The thawing of the bank most exposed to the sun would favor greater erosion in that direction. A tilting of the landmass would favor a widening of the meanders on the down-tilted side, but any moderate tilting would have but little direct effect on the lateral erosion of a stream. In affecting the carrying power of the tributaries, however, a notable shifting in the direction of the down-tilting should result.

However, these processes, singly or combined, cannot account for all the peculiarities observed in the Alaska streams and in the lower Yukon, the most striking instance of unbalanced erosion, there is no evidence of their operation at all.

Reasoning that, if such notable difference in lateral erosion should be effected in high latitudes, rivers in lower latitudes should show the result of the same influence to some lesser degree, the Missouri River was chosen for comparison. The Missouri has a well-developed flood plain, meanders broadly, and has been engaged in progressive de-gradation probably since late Pleistocene time. The summary results of all the factors directing its erosion during this period of time should be expressed in the present condition of the river and its valley.

The distribution of the flood plain with respect to the river was measured on the compiled Index Map of the Missouri River Commission, between Sioux City, Ia., and Kansas City, Mo. The results were:

Between the river and the left valley wall, 1,370 sq. miles.
Between the river and right valley wall, 312 sq. miles.

In the upper part of the river, from Fort Benton, Mont., to Sioux City, Ia., we still have what might be termed the first generation of meanders, that is, they are still in a developmental stage and swing first against one valley wall and then the other.

The form of these meanders, of such simple history, is significant. Those to the left of the mean axis of the stream are as a rule sharper than those to the right, the river is in contact with the right valley wall more often than with the left, and those reaches where the river is in contact with the right valley are longer generally than those where the contact is with the left valley wall. This latter characteristic becomes more and more notable down-stream.

In the reach from Fort Benton to Sioux City meanders have been cut off in five cases. Of these, four are on the left side of the stream and one on the right. However, in the case of the individual meander on the right, instead of receding from the loop, as is normal when cut off by differential migration, the river is at present encroaching upon it, making it very probable that the case represents domestic piracy rather than the former process. In each test stronger erosion on the right seems evident.

The influence of the earth's rotation, then, is to unbalance the lateral erosion of streams, in the northern hemisphere directing the stronger erosion on the right bank, and in the southern, on the left. The deflective force is much stronger in the higher latitudes. Its influence is felt by streams both with and without meandering courses and is most effective in streams with straight courses. Examination of streams in both high and mean latitudes reveals conditions of unbalanced lateral erosion that seem best interpreted as the result of rotational deflection.

GLACIAL LAKES OF PUGET SOUND

PRELIMINARY PAPER

J. HARLEN BRETZ

On the western margin of the North American continent an uninterrupted fjord coast extends from Cross Sound in the Alaskan panhandle southward to Puget Sound in the state of Washington. The topographic expression of the whole extent of coast line is glacial,[1] but the Strait of Juan de Fuca appears to separate this coast into (1) a region of predominant glacial erosion and (2) a region where glacial deposition much exceeded the erosion of the ice. Puget Sound is this latter region to a unit.

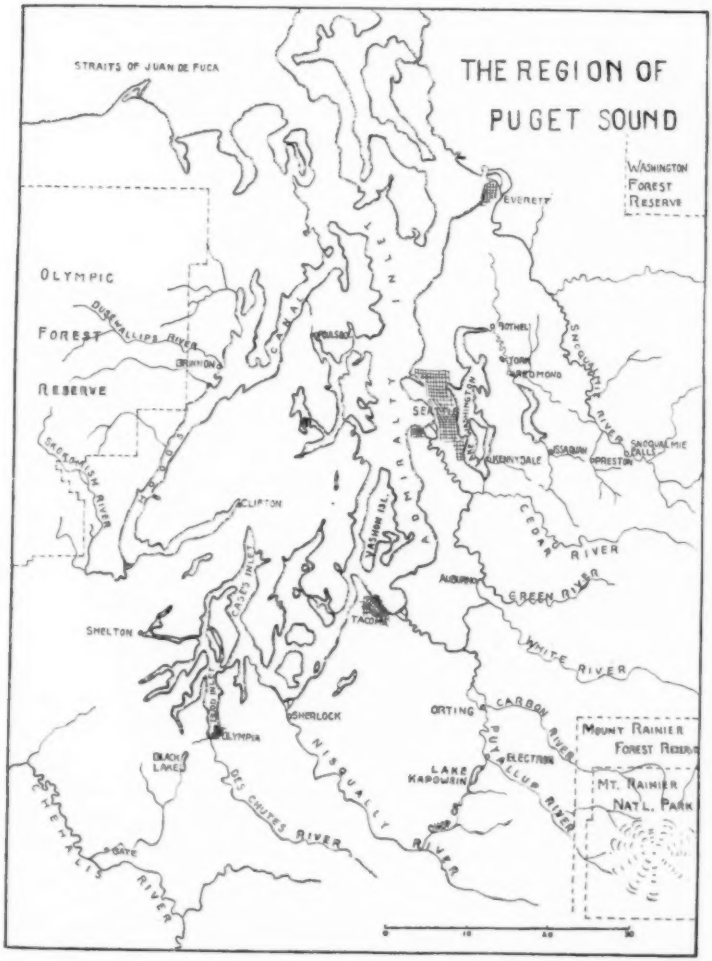
The complexly fingered arm of the sea known as Puget Sound lies in meridionally oriented troughs whose walls sometimes rise in sea cliffs 300 feet A.T. and whose maximum depths are approximately 1,000 feet below sea-level. To sea-level, at least, these fjord-like troughs are largely drift-walled. The larger stream valleys, lake valleys, and divides of the Puget Sound region are likewise fashioned in glacially transported material, and all share the roughly meridional orientation.

It is established that the ice of the last glaciation of Puget Sound was derived largely from snowfields to the north.[2] The axial lines of the grooved topography parallel the striae, and the ridges and valleys are at least veneered and often deeply covered by the youngest till of the region. The Vashon[3] ice which deposited that till sheet must have been related to the genesis of this peculiar and persistent topography in one of three ways: (1) the ice conformed closely to the ridges and grooves which were fashioned before its advent; (2) the last glaciation produced the present topography by erosion of an older and more nearly uniform drift surface; or (3) the Vashon

[1] G. K. Gilbert, "Glaciers and Glaciation," *Harriman Alaska Expedition.*

[2] Bailey Willis and G. O. Smith, "Tacoma Folio, No. 54," *U.S. Geological Survey.*

[3] Willis names the last glaciation of Puget Sound from Vashon Island, where its till is typically developed ("Tacoma Folio," *U.S. Geological Survey*).


THE REGION OF
PUGET SOUND
STRAITS OF JUAN DE FUCA
WASHINGTON
FOREST
RESERVE
EVERETT
OLYMPIC
FOREST
RESERVE
DUNGENESS RIVER
DUNGENESS
PORT ANGELES
PORT TOWNSEND
DISCOVERY BAY
STRAIT OF JUAN DE FUCA
PUGET SOUND
HOOD CANAL
QUILCENE
BREMERTON
SEATTLE
BOTHELL
KIRKLAND
REDMOND
SNOQUALMIE RIVER
SNOQUALMIE FALLS
FALL CITY
ISSAQUAH
PRESTON
RENTON
HOQUIAM RIVER
HOQUIAM
ABERDEEN
CHEHALIS RIVER
MONTESANO
ELMA
ELDON
OLYMPIA
CLIFTON
CEDAR RIVER
AUBURN
GREEN RIVER
TACOMA
SHELTON
WHITE RIVER
ORTING
CARBON RIVER
PUYALLUP RIVER
ELECTRON
MOUNT RAINIER
FOREST RESERVE
MT. RAINIER
NAT'L. PARK
SHERLOCK
BLACK
LAKES
LAKE
KAPOWSIN
DESCHUTES RIVER
NISQUALLY RIVER
GATE
CHEHALIS RIVER
0
10
20
30

invasion modified an older drift topography to that now existing. As to which of the explanations is correct, this paper is not concerned. For present purposes it is sufficient to show that, with ablation of the Vashon ice sheet, the topography essentially as it now is was exposed.

The depression occupied by Puget Sound is inclosed on the west by the Olympic Mountains, on the south by a low gravel plain between the Sound and the Chehalis River, and on the east by the Cascade Mountains. At the maximum of Vashon glaciation, the ice sheet filled the entire depression, extending south of Olympia at the most southern tip of Puget Sound. Outwash at this maximum stage is largely responsible for the extensive gravel plain constituting the Chehalis-Sound divide.

When retreat of the front of the Vashon ice sheet began and exposure of the depression of Puget Sound progressed northward, water accumulated at the ice front to a depth sufficient to escape across the gravel plain southward to the Chehalis River. The meridional orientation of hills and valleys exposed by ice retreat, together with the fact that the ridges were higher than the outwash plain across which drainage escaped, caused the ponded water to accumulate in long arms and inlets quite like those of the Sound today. Troughs without opening southward and closed by ice at the north would contain independent water-bodies whose levels were controlled by the lowest place in their basin rims. Troughs with openings lower than the Chehalis-Sound divide would become part of a complexly branched lake, whose level was controlled by the lowest altitude of that divide.

How far north did the retreating fingered ice front serve to hold up the increasing glacial waters to the discharge-way across to the Chehalis River? Postulating an uncrevassed ice sheet of sufficient thickness, the dam should have been effective during retreat throughout the entire length of the Sound. Denying this postulate, subglacial drainage of the lake seaward (northward) might have occurred early in ice retreat, in the manner described by Russell for lakes in the Malaspina Glacier at the foot of the Chaix Hills.[1] Investigation

[1] I. C. Russell, "Second Expedition to Mount Saint Elias," *Thirteenth Annual Report, U.S. Geological Survey*, Part II. Suggested by Willis in personal communication to writer.

of the glacial features of Puget Sound has hardly gone far enough to justify definite conclusions on this question as yet. A brief description of the records of the principal glacial lakes of the region, as far as they have been studied, is given here, since such data alone can substantiate the preceding hypotheses and answer the question raised.

GLACIAL LAKES OF HOOD'S CANAL

The form of this remarkable body of sea water is that of a great hook, the main portion of which is 50 miles in length and about two miles in its notably constant width. The broad valley of the Skokomish River joins the southern tip of the Canal from the west in much the same fashion that the arm which makes the hook form joins from the east. The topographic disposition of the trough of Hood's Canal and the two tributary valleys is perfectly adapted to the production of a lake of glacial water in front of the ice during its retreat. The inclosing drift bluffs at the head of the Canal are about 350 feet high, and from this altitude a gravel plain slopes gently south toward Shelton. Two or three channels across it are known in part, and probably represent escape of water from the earliest and highest ponding at the head of the Canal. This early lake was held to the level of about 350 feet in the main trough and up the two north-trending arms, while the ice retreated northward. The enlarging water-body reached the head of the northeastern arm before any important change of level occurred. Near Clifton a pass was exposed to Case's Inlet southward, lower than the gravel plain to Shelton, and, with exposure, it became the discharge-way of the glacial lake of Hood's Canal. The very distinct channel here is 60 feet deep, the col in it lying at about 220 feet A.T. The operation of the Clifton outlet determined a new lake level, and may thus define the second stage of the glacial lake of Hood's Canal. Discharge from both the first and second stages was into the larger lake held back of the Chehalis-Sound divide.

The bluffs of Hood's Canal, followed northward, continue everywhere sufficiently high to have held the glacial waters up to the Clifton outlet for almost the entire length of the Canal. The ridge and trough arrangement of the topography is interrupted in the broadest part of the peninsula between Hood's Canal and Admiralty

Inlet by a group of high hills of igneous rock. North of them the prevailing meridional orientation again occurs, and in the southern portion of one such trough, Dogfish (Liberty) Bay lies today. This till trough continues north across the peninsula to Hood's Canal with a swamp col near midlength 120 feet A.T. Here then was a pass lower than the Clifton outlet, and with its exposure the level of the ponded glacial waters fell and the Clifton channel was abandoned.

The Poulsbo channel, the outlet from Hood's Canal to Dogfish Bay, has valley sides that rise to an altitude of 200 feet above the col. A definite stream floor fragment lies on the east side of the summit, at about 150 feet A.T.

At the mouth of the Dusewallips River which enters Hood's Canal from the Olympics, occurs a portion of an ancient delta of that stream, the seaward front rising quite steeply from marine water to an even crest of 120 feet. It lies on the north side of the valley mouth, the form and extent being well shown in 20-foot contours on chart 6,450 of the U.S. Coast and Geodetic Survey. Save for one post-glacial ravine, no break occurs in the plane surface which reaches back at least two miles with an almost imperceptible slope upstream. The surface of the plain is everywhere of sand and stream-rolled gravel. Obviously this delta correlates with the 120-foot level of the Poulsbo channel. The significance of the 120-foot level and of the 150-foot terrace in the Poulsbo channel will be discussed later.

GLACIAL LAKE OF PUYALLUP VALLEY

One of the larger meridional troughs of the region lies parallel to Admiralty Inlet on the east. It is occupied in its northern extent by Lake Washington and, retaining its character of a till trough, reaches as far southward as Orting. Originally an arm of the Sound, post-glacial alluviation has silted it up. The most southern break in the valley walls is at Tacoma, and the topographic conditions south of this are such that a local glacial lake must have existed in the valley early in the final retreat. This portion of the trough is properly termed the Puyallup Valley.

The only known record of the Puyallup glacial lake is its outlet valley. In this valley lie Lake Kapowsin and Ohop Creek. A col just south of Lake Kapowsin causes a small stream entering there

from the east to divide, one portion flowing north to the shallow linear lake and thence to the Puyallup River, the other reaching Ohop Creek and draining into the Nisqually River. The altitude of the col is 620 feet, above which the old valley bluffs rise 350 feet. It is probable that the deposits of this stream have raised the level of the Kapowsin outlet. The western margin of the Puyallup Valley northward toward Tacoma averages only 550 feet A.T. and Lake Puyallup must have early abandoned the Kapowsin outlet and found escape through spillways westward.

With discharge by either route, the waters of the lake were tributary to the larger lake held back of the Chehalis-Sound divide. When the ice dam failed to be effective, the Puyallup Valley became one of the group of flooded troughs constituting the major glacial lake of Puget Sound.

GLACIAL LAKES OF THE SAMMAMISH VALLEY

The Sammamish trough lies parallel to Lake Washington on the east. It has its inception ten miles north of Bothel and gradually deepens to its abrupt termination near Issaquah. The modern Lake Sammamish, seven miles long and 35 feet A.T., lies well to the south in the valley, a wooded swamp occupying the part north of the lake to Bothel and a creek draining the remaining length. The valley's southern portion is inclosed by three high rock hills, rising 1,500, 2,000, and about 2,500 feet A.T. Two low passes of preglacial origin cross the inter-hill areas. Beetling cliffs confine them in places.

East of Issaquah, altitude 90 feet, and on the northern flank of the largest of the three rock hills, is a considerable level area with an altitude of 425 feet. Coarse gravels and cobbles of glacial drift compose the surface, and are exposed in strata in several sections. Back from the margin of this deposit is a terrace 20 feet higher and with a still more extensive level surface continuing eastward. The face of the gravel deposit comprises the eastern wall of the Sammamish trough at Issaquah, and is dissected to a depth of about 300 feet by the stream which here enters from the east. Followed upstream, this creek is found, four miles out of Issaquah, to be wandering through a wide, flat-bottomed, swampy valley in which the stream appears incongru-

ously small and ineffective. The valley floor here is about 50 feet higher than the gravel deposit with which it doubtless correlates.

At Preston, this old floor suddenly ends at 540 feet A.T., with the valley at full width. A descent of about 100 feet occurs to Raging River which comes in from the southeast and turns north at this point. But the level of the valley floor at Preston is continued, in the form of terraces, up the Raging River for four or five miles to the point where the grade of the stream has brought it up to the level of the Preston Valley.

At the time that Raging River was discharging into the Sammamish depression, it seems probable that an ice tongue occupied the trough, and held back the river to the level of the deposit referred to above. This deposit, hardly to be considered as a delta, is the oldest record of glacial waters in the Sammamish Valley.

A glacial lake of limited extent must have succeeded the ice tongue in the southern portion of Sammamish Valley, and discharged southward through the rock-walled valleys noted, both of which are floored with coarse, rounded gravel. The lowest altitude at which this lake could have existed with these discharge-ways is about 315 feet.

A channel exists across the till ridge between lakes Sammamish and Washington at the north base of Newcastle Hill, the lowest of the three rock hills noted. It is floored with coarse gravels. Another channel a mile north of the one just noted contains Phantom and Larsen lakes, and is floored with swamp deposits. Both are about 300 feet A.T., and must have existed contemporaneously or nearly so with the southward escape.

A third abandoned channel across the till ridge between the two parallel valleys exists near York, or Willows, a few miles north of Redmond. The summit of the York channel is 160 feet A.T. and no perceptible slope exists in the swampy bottom to the west. This fact argues a similar level of ponded water in the Lake Washington valley. Lake Washington's surface today is 130 feet lower than the col.

Correlating with the York channel is the highest level of the Redmond delta, a heavy gravel deposit which lies a mile east of the town of Redmond. This delta occurs at the debouchure of a former chan-

nel of Snoqualmie River into the Sammamish Valley. It is a gravel plateau, one square mile in area, rising abruptly, along its western and northern margins, from the lake valley bottom. Its summit profile is made up of four levels, 120, 130, 140, and 160 feet A.T. Excavations on the lakeward face show the entire height of about 70 feet to be composed of stream gravels, and in at least one case to have foreset bed structure. The terraced surface clearly records dissection of higher levels in the development of lower ones, and proves their development in a lowering water-body.

The relation of the highest level of the Redmond delta to the York channel has been noted. For the remaining levels, 140, 130, and 120 feet A.T., the present outlet past Bothel must have served. The valley here is one of the few till troughs of Vashon or earlier date, whose orientation is other than meridional. It must have presented so low an escapeway on its exposure that it cannot account for the three lower levels of the Redmond delta. Their explanation must be sought elsewhere, and will be discussed under the following heading.

GLACIAL LAKE OF PUGET SOUND—LAKE RUSSELL

It is now time to examine the records of the master lake of Puget Sound, whose level was determined by the Chehalis-Sound divide, and which in turn controlled the descending levels of several, if not all, of the minor lakes of the region.

This lake began its existence when the withdrawal of the Vashon ice sheet first exposed surfaces lower than the great gravel outwash plains between the Sound and the Chehalis Valley. Across these plains all escaping water from the Vashon glacier must have flowed as long as the ice remained a dam at the north. As already noted, there is the possibility of escape of drainage northward through englacial or subglacial tunnels at a level lower than the Chehalis-Sound divide, before the clearing of the northern portion of the Sound occurred. The northern limit of this great lake thus is at present quite indefinite.

The outlet for all water escaping southward from fresh-water bodies in Puget Sound lies southwest of Olympia, through the col between the Sound and the Chehalis River, with an elevation of 120 feet A.T.

A swamp at the col drains both north and south. Within two miles of Puget Sound drainage from this swamp flows south to the Chehalis River and thence to the Pacific Ocean, 50 miles distant.

The narrowest place in the channel of the glacial stream which discharged over the divide is close to its inception, about 1½ miles from Budd's Inlet. Here the width of the 120-foot channel is less than one-fourth of a mile. This is cut in the bed of a considerably wider channel, whose floor is 160 feet A.T. A definite terrace occurs here, and also in the swamp a mile distant at 140 feet. These three levels are seen repeatedly in the 17 miles of channel length, though their altitude descends and their distinctness is less marked farther south. The ancient outlet today contains Percival Creek north of the col, and Black Lake and Black River south of it.

At Gate, the Black Lake outlet channel joins the wide Chehalis Valley. At the debouchure occurs a considerable area of gravel spreading out into the larger valley from the north. The deposit presents a rather abrupt face down the valley. Its surface altitude is approximately 100 feet above sea-level. Farther down the Chehalis Valley, glacial gravels occur only at the mouths of tributary valleys from the north, none being found in a careful search for five miles immediately below Gate.

The genesis of the Gate gravels is evidently associated with the operation of the Black Lake outlet and their deposit here suggests slack water in the Chehalis Valley, standing at an altitude at Gate of about 100 feet.

The suggestion of standing water at Gate and in the Chehalis Valley, much beyond the limits of glaciation, and so topographically placed that ice could not close it if it were glaciated, turns one to a consideration of the sea-level at the time of Vashon glaciation and retreat.

In the study of the physiography of Puget Sound, various shell-bearing terrace fragments have been observed. Willis notes the occurrence of the lowest, 15–20 feet above present mean tide,[1] and Arnold has recorded one 40 feet above sea-level on the west side of the Olympic Mountains.[2] Terraces at both of these levels have

[1] Bailey Willis and G. O. Smith, *op. cit.*

[2] Ralph Arnold, "Geological Reconnaissance of the Olympic Peninsula," *Bull. Geol. Soc. Am.*, XVII.

been repeatedly observed by the writer, occurring on all important inlets of the Sound. Shell-bearing terraces at higher levels, though rarer, have been found at about 60 and 80 feet, and in three places 100 feet above present tide.

Of the marine shell-bearing terraces at the highest level, two are on the west side of Hood's Canal, and one at Tumwater on Budd's Inlet. On one of the Hood's Canal 100-foot terraces, the sod and forest soil are literally a mass of comminuted shell fragments to the depth of a few inches. The 80-foot terrace is present immediately below it.

Unless error has been made in these observations, there is here conclusive evidence that at some time subsequent to the fresh-water occupancy of Puget Sound's southern valleys, the land was 100 feet lower than now.

From the rare occurrence of the consecutively higher marine terraces of Puget Sound, and from the lack of any evidence to the contrary, it has been assumed that the series represents successive stages in a rising of the land which has been in progress throughout post-glacial time. On this supposition, the 100-foot terrace represents the level of sea water on first entrance into the Sound after the ice retreat from its northern portion. The 100-foot gravels at Gate and the 100-foot marine terraces of the Sound seem good evidence that the entire region was that much lower when the greater lake of Puget Sound discharged southward across the Chehalis-Sound divide during the retreat of the Vashon ice sheet. This lake then was but 20 feet above the sea at its lowest stage.

It is well established by the outlet channel that static water was held to its levels in the southern part of the Sound by ice in Admiralty Inlet during Vashon retreat. The limited amount of examination thus far possible has shown four rivers of the region to possess deltas at one or more levels between 120 feet and 160 feet A.T. The Des Chutes River has an old delta plain in the southern part of Olympia 160 to 170 feet high, and the Nisqually River dissects an old delta at Sherlock, three miles back from the present coast, the summit plain of which is about 160 feet high. Both deltas correlate with the 160-foot terrace in the outlet near Black Lake. They have been examined only cursorily thus far, and nothing is known concerninng lower stages.

Farther north occur the Redmond and Brinnon deltas, the former with correlating terraces for the three stages of the lake indicated by the outlet, the latter with but the lowest stage recorded. Associated with these deltas are respectively the York and Bothel, and the Poulsbo channels at appropriate altitudes, and each leading into a valley open through to the Black Lake outlet at the south.

Though the evidence of the two northern deltas may perhaps be of insufficient weight to establish the extent of the master lake as far north in the Sound as the Bothel and Poulsbo channels, yet it is quite suggestive of such extension. The levels must otherwise be explained as a coincidence of local ponding, and the greater lake must in such case be considered as having lowered from the Black Lake outlet earlier in the ice retreat, by tunnel drainage northward.

It is of much interest to note that there is nothing in any collected data concerning the various glacial lakes or the terraces of early marine occupancy which suggests tilting or warping of the region in the uplift which has taken place.

It seems fitting that to this lake of Puget Sound, with outlet southward through Black Lake channel and with levels controlled by that channel, a name should be given in tribute to the work of a geologist to whom our knowledge of the physiography of western North America must always be deeply indebted. In memory of Israel Cook Russell may this water body be known as *Lake Russell*.

In an article by Upham in the *American Geologist*,[1] the Black Lake outlet is noted and the suggestion made that a glacial lake probably existed in Puget Sound and discharged through the channel. Upham supposed the col to be 170 feet high. This article was not seen until the work on which the present article is based was all but completed, the outlet region having already been examined three times. Though having no influence on this work, it is hereby acknowledged as the first published notice of the existence of Lake Russell.

The writer is indebted to Mr. Bailey Willis for careful examination and criticism of the data presented herewith, and for valuable suggestions which have given broader conceptions and have modified conclusions in this paper.

[1] Warren Upham, "Glacial and Modified Drift in Seattle, Tacoma, and Olympia," *American Geologist*, XXIV, No. 4.

ON THE GLACIAL ORIGIN OF HURONIAN ROCKS OF NIPISSING, ONTARIO

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In the early (1846 ff.) reports of the Canadian Geological Survey there appear descriptions by Sir William Logan of a series of non-fossiliferous clastic rocks found on the west shore of Lake Temiskaming and north of Lake Huron. Logan correlated the rocks of the two localities and gave them the name Huronian. He believed them to be younger than and made up partly of detritus from the Laurentian, and his conclusions have been verified by later observers.

Recently these rocks have attracted more than local interest on account of the discovery of rich silver veins at Cobalt. As a result of their economic importance the rocks have been subjected to much closer examination than before and many interesting features have been noted. Among these are peculiar characters which are strongly suggestive of the existence of glaciers in Nipissing in early Huronian times. Dr. A. P. Coleman[1] who has made a study of these rocks from the standpoint of the glacialist, has gathered evidence from which he concludes that there is no doubt of the glacial origin of the basal conglomerate of the lower Huronian. It is purposed here to present some facts which bear on this question.

The chief rocks in this district are of the Archean and Algonkian groups. These are separated by a very marked unconformity and the interval was doubtless the greatest which occurred in the pre-Cambrian times. There is no good reason to doubt that for a long period of time the Archean rocks were being worn down by all or any of the erosive agents now active.

The Huronian series doubtless represent a portion of the secondary rocks thus formed, and they are entirely composed of detrital material. They are conveniently grouped into an upper and a lower series,

[1] "The Lower Huronian Ice Age," *Jour. Geol.*, XVI (1908), 149–58.

which are generally conformable but in some localities separated by a slight unconformity.

The upper series is made up largely of medium-grained feldspathic quartzite with a little conglomeratic material. It presents no unusual feature and doubtless represents the hardened accumulation of a feldspathic sand derived from siliceous holocrystalline igneous rocks of the Laurentian group.

The lower series is made up largely of conglomerate, shale, graywacke, and feldspathic quartzite. In many cases there is gradual

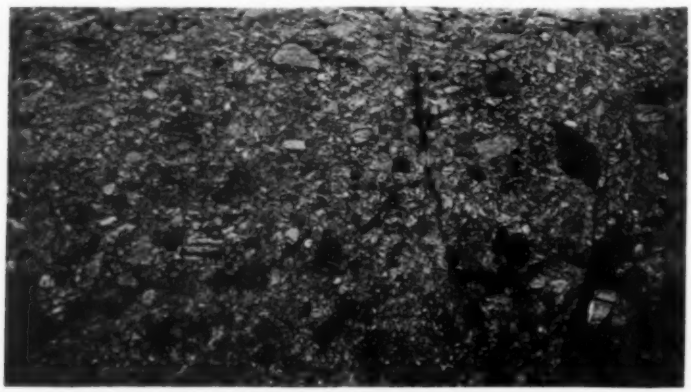

FIG. 1.—Huronian conglomerate near Temagami, Ont.

gradation vertically from one of these types to another. Less often there is a sharp division line. The composition of one stratum is often fairly constant for some distance; but in some cases a distinct change takes place in a few feet laterally as well as vertically.

The shales are for the most part of gray color, less often greenish black. Occasionally they are interbanded with layers of purple, green, and pale-gray colors. The chief recognizable minerals are quartz and altered feldspars, minute scales of chlorite and sericite, and small grains of epidote, titanite, and iron ores. In mineralogical and chemical composition they are not unlike green shales of other formations.

The quartzites are in most instances feldspathic and grade insen-

sibly into typical arkoses. They are usually very massive, fine to medium grained, and not unlike light-colored granite in appearance. It is often very difficult to determine their structure as there are seldom well-marked bedding planes. There are however instances in which the bedding is indicated by variations in the size and relative proportions of the various grains and other cases in which it is indicated by horizontal jointing. The rock is very largely composed of quartz and feldspar. Sericite and kaolin are prominent in light-colored varieties and chlorite in the darker. Titanite and iron

FIG. 2.—Huronian conglomerate, Temagami, Ont. Steel scale (in book) is one foot long.

ores are usually present in small quantity. The feldspar and quartz grains are often well rounded but quite as frequently angular or sub-angular.

Closely allied to the shales and arkoses are the graywackes. The chief recognizable constituents in these are feldspar, quartz, a dark chlorite, and a pale-colored mica. Less abundant are small particles of iron ore and epidote, while pyroxene and amphibole are rare. With the minerals are angular and rounded rock particles of various sizes. Rock of this type in some instances is found in massive beds of uniform character, very fine grained and of gray to greenish color. Similar material forms the matrix of much of the bowlder conglomerate.

FIG. 3.—Huronian conglomerate, Buffalo Mine, Cobalt, Ont. A common type, little evidence of stratification.

The conglomerate is remarkable for its heterogeneous appearance. Not only are the bowlders of a great variety of types but in many cases they show no evidence of arrangement according to size. Frequently one finds bowlders a foot in diameter scattered irregularly and sparsely through an aphanitic matrix of shale or graywacke, thus simulating glacial deposits. In other cases there are thick beds of shale quite free from such erratics. There are also beds of bowlders of nearly equal size packed close together and with but little of fine-grained matrix,

FIG. 4.—Huronian conglomerate, Buffalo Mine, Cobalt, Ont. A weathered surface of coarse facies.

as in an ordinary water accumulation of coarse gravel. In some instances the aphanitic beds are distinctly laminated as in ordinary water-laid clay, while again similar material forms a compact rock lacking in well-developed bedding planes.

As a general rule the large bowlders are well rounded or subangular; but there are occasional streaks containing markedly angular fragments. Dr. Coleman found some bowlders at Cobalt which show striae and concaved surfaces.

The matrix of the conglomerate, which is often graywacke and less often shale, contains numerous angular particles of quartz, feldspar, chert, and felsites. Particles of such shape are very characteristic of, though they are by no means found only in, glacial débris.

Where the contact of the conglomerate with underlying rocks has been found there is a noteworthy lack of alteration in the older rocks. If they were deeply disintegrated by surface weathering the material must have been removed by a very efficient agent. This again suggests ice action. In a few of the contacts the line of demarcation is less distinct, as is ordinarily the case with unconformities in water-laid sediments. Naturally the contacts of the latter type are not so likely to be found as those of the former.

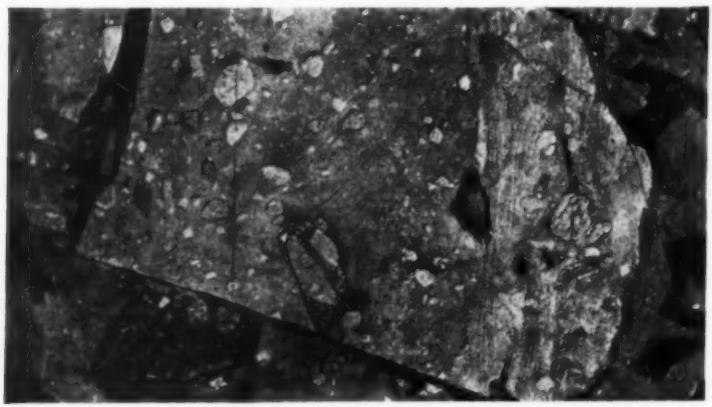

FIG. 5.—Huronian conglomerate, Coniagas Mine, Cobalt, Ont. A horizontal exposure.

There has not yet been found a smooth or striated floor. The basal conglomerate, in some cases at least, has been formed *in situ* and is made up of detritus from the immediately adjacent rocks.

Professor Coleman does not consider that the lack of discovery of a characteristic glacial floor precludes the possibility of the material having been placed by ice, and refers to well-known instances in which such a floor is lacking.

The localities specially mentioned by Dr. Coleman are Cobalt and Temagami. Cobalt Lake, on which the town is situated, lies almost entirely in Huronian conglomerate. The conglomerate in turn lies in a deeper valley formed by rocks of the Keewatin group. It might be expected therefore that the coarser material in the conglomerates

would be largely detritus from these old greenstones and cherts; but such is by no means the case. The basal portion is made up

FIG. 6.—Huronian conglomerate on Keewatin slate. Near Temagami Ont.

FIG. 7.—Coarse conglomerate on greywacke (Huronian). Temagami, Ont.

very largely of material similar to that which inclosed the old valley; but the greater portion of both bowlders and matrix is quite different. There are not now exposed any near-by hills from which these mate-

rials might have been brought down, nor is there good reason to believe that such hills existed in Huronian times. The nearest outcrops of Laurentian rocks from which many of the bowlders may have been derived are some miles distant. Many of the large bowlders are quite unlike any rocks which have been found in place in the district. Evidently ice was the most competent agent to bring such materials to their present position, and to deposit them in such a heterogeneous manner.

FIG. 8.—Huronian conglomerate, Trethewey Mine, Cobalt, Ont. Shows stratified and unstratified portions. Such well-banded portions are of quite small extent as compared with the unstratified. One of the streaks contains distinctly angular fragments.

At Temagami the conglomerate lies on Keewatin schists and at its base contains numerous fragments of them. The conglomerate also contains numerous rounded and subangular bowlders of rocks not found close by. The underlying rock presents a fairly fresh but not a smooth surface. The matrix of the basal conglomerate contains numerous well-formed rhombohedra of siderite, and similar crystals are abundant in shale and quartzite beds in the conglomerate. They were evidently derived by weathering from the adjacent iron formation and the crystals were growing freely contemporaneous with the mechanical deposition of clay, sand, and bowlders. It is probable

therefore that the conglomerate was formed under water and that there was carbonate in solution. If the larger erratics were brought by ice it was probably not land ice.

SUMMARY

In appearance the conglomerate-quartzite-shale series of the Huronian represents nothing so closely as compacted glacial and glacio-fluvial débris. The finding of striated and soled pebbles confirms the supposition of such an origin. The character of the contacts thus far found do not disprove that glaciers placed the basal conglomerate, though they suggest that such was not the case.

There are some sudden transitions from shale to coarse conglomerate which suggest that the earlier deposits may have been overridden by land ice. It seems probable however that part of the material was deposited under water and that floating ice contributed its load of glacier-derived material.

There is no reason for supposing that the thick bowlder-free beds of shale and graywacke are not ordinary water-laid sediments, though they may contain glacial floor.

Editorial

Most good causes, as they come into popular favor, suffer from diversions, if not perversions, in the interest of other causes. Just now the good cause of the conservation of natural resources has reason to file a protest against being made the victim of the old device of promoting a weaker issue by a perverted use of the popularity of a stronger one. After a normal growth of two decades under the scientific guidance of the national Geological Survey, the doctrine of conservation has recently blossomed out into wide popular favor. This special blossoming has not been without artificial fertilizers from other than strictly scientific sources, but that need count little here or there if the blossoming be left to lead on to natural fruitage without hybridization. Now, however, come diversions and perversions. The protection of natural values against wastage is one thing, the possession of these values is quite another thing. The best conservation may not be correlated with the best ownership, all things considered. Ownership, desirable on other accounts, may be an obstacle to conservation, and ownership, otherwise undesirable, may be tributary to conservation. This is so because, in their fundamental nature, the problems of conservation and the problems of possession are distinct questions, each to be solved in its own way and on its own basis. They center in separate fields. The conservation of natural resources centers in the scientific and the technical; the right of ownership and the most desirable distribution of ownership center in the political and the sociological. The best conservation of the soil is not necessarily dependent on the most desirable partition of the land. The small farmer often impoverishes his farm, while the estate of the millionaire fattens under scientific management. To divide Alaska into 90,000,000 moieties and give each of us one, would not settle the problem of the highest utilization of the Alaskan resources. To form an absolute monopoly with 90,000,000 stockholders—call it "government" or otherwise, as you please—would still leave the problem of conservation untouched. To permit fewer individuals and more corporations to pay the price and divide the ownership,

in accordance with our present practice, however proportioned, would equally leave the problem of conservation to be worked out on its own grounds. And so, though in like manner all questions of the possession and distribution of values be marshaled under extreme individuality, extreme monopoly, or some combination of individuals and corporations lying between these extremes, all are alike political and sociological in nature and, however they may issue in practice, they leave the scientific and technical problems of conservation of natural resources to be solved on their own bases. And these solutions must be fundamentally much the same under any political or sociological system.

So obvious is all this that it can only be a careless lapse into confusion of thought, or else a wilful perversion of what is legitimate in the arts of persuasion, for an advocate of political or sociological measures to glide without a note of warning from a conservational premise which commands universal assent to a political conclusion respecting ownership or distribution of values which has no logical relation to conservation, and may even be incompatible with its highest realization. In recent months we have perhaps met such perversions or confusions of thought quite as often as legitimate arguments for true conservation. Fallacies usually reveal themselves in the end and hurt the cause in behalf of which they are urged, and these perversions must ultimately stand in the way of the wisest provisions for the distribution of natural values in behalf of which they are putatively invoked. No class of men bear a more urgent commission to keep the currents of thought clear and ethical respecting our natural resources than geologists, for, more than any others, they have, as a matter of history, been the fathers of the real conservation movement. Hence this note on the untoward set of a sinister current.

T. C. C.

Reviews

Comparison of North American and European Glacial Deposits. By Frank Leverett, Ann Arbor, Mich. *Zeits. f. Gletscherkunde* (1910), IV, 241–316; Pls. V.

Intercontinental comparisons of this class may be made from the viewpoint of an individual worker, or from that of a representative of a special class of workers, or from that of an analyst of the whole body of current conceptions. Each viewpoint has its appropriate place and value, and each comparison must be adjudged on its own basis. The comparison of Mr. Leverett is individual rather than representative or composite. This gives occasion to note the reach of the personal studies that form the basis of the author's perspective. No one is more intimately conversant with the later glacial deposits of the plains of the United States from the Alleghenies to the Mississippi than is the author of this comparison. With the equivalent deposits east of the Appalachians, west of the Mississippi, and north of the national boundary, the author's familiarity comes rather from occasional excursions and secondary sources than from personal studies. With the older Labradorean formations east of the Mississippi the author's familiarity is also intensive, and this intimate knowledge extends measurably to the tract closely bordering the Mississippi on the west, but not in equal degree to the formations of the Missouri basin, to the glacio-fluvial deposits of the Lower Mississippi valley, or to those of the Atlantic coast. The montane field of western America lies outside the author's individual purview.

To this intensive basis in American study, Mr. Leverett has recently added a year's inspection of the European formations, with Berlin as a working center and German interpretations as a point of departure. His field studies lay chiefly in the German lowlands and in the Alps, with a very cursory glance at the British field.

These salient features of the author's experience may serve to orient the psychologic plane from which the comparison is made and to foreshadow the selection, emphasis, and coloration which might naturally arise from the author's point of view.

In full harmony with these, the preliminary glance over the makeup of the paper brings at once to view the obvious fruits of the intensive habit.

These constitute a notable part—and, it will be agreed, a most valuable part—of the paper. As by instinct, here and there the author drops into details of location and measurement, and the text takes shape more as a record of local facts than as a generalized intercontinental comparison, as on pp. 266–73, where the successive paragraphs are headed, "Basel," "Eglisau," "Leutkirch," "Drau Valley," "Lake Garda," "Cantù, Italy," "Dora Baltea," "Rivoli," and "Bièvre-Valloire"; with similar local treatment on pp. 283–95, and elsewhere. Besides contributing such local observations from the viewpoint of an American glacialist, the author earns our thanks by giving a convenient map of the limits of "The Old Drift," "The Middle Drift," and "The Young Drift" of the German lowland, to the construction of which he himself appears to have made local contributions.

The comparison itself is introduced under the head of "The Oldest Drift." America here makes its bow under an apology, as it were, for the buried state of the oldest drift in the Keewatin field and the scanty, scattered, weathered, remnant nature of the Jerseyan drift. But in reality these ragged weathered remnants tell the very story of age that most becomes a venerable drift. It is hard to pass complacently over so light a treatment of the worn and aged Jerseyan formation. To put the still more scant remnants of the old drift of the Allegheny Valley in their place as more representative but emphasizes the personal viewpoint which runs through the whole comparison and gives it at once its values and its limitations.

In assembling the group of oldest glacial deposits of the two continents, the old drift of the Allegheny basin (with some reservation), the Jerseyan east of the Alleghenies, and the pre-Kansan of the Mississippi Valley, as the American correlatives, are matched with the Scånian of north Germany, the Günz of the Alps, and the older Deckenschotter of the Alpine foreland. The oldest Deckenschotter however has a better correlative in the oldest member of the Columbian group, bordering the Jerseyan drift, both being outwash aprons, and in the massive Natchez formation of the Mississippi outwash train, and better still—because of similar topographic relations—in the remnants of old outwash sheets that spread forth from the ancient glaciers of the Uinta, Wasatch, and other montane centers of the Cordilleras, which are unmentioned. It would be ungracious to lay stress on this, did not the American side of the comparison, and withal the rounder and truer view, suffer from the neglect of some of America's most significant formations even when they have been fairly well worked. It may be noted also that the Günz drift has its best American correlatives in the Cordilleras.

For the first interglacial series, the Aftonian of America is compared

with the Paludinenbank of Germany, the Norfolkian of England, and the Günz-Mindel interglacial beds of the Alpine region.

As the second glacial series, the Kansan of the Keewatin field, and, questionably, the old deposits of the Allegheny Valley as a doubtful representative of the Labradorean field, are brought into comparison with the Lower Diluvium of the German lowlands, the Old Drift of England, the Mindel of the Alps, and the younger Deckenschotter as the associated outwash deposit of the last. The American correlatives of the last, in kind, are passed over.

The representatives of the second interglacial stage are the Yarmouth and the pre-Illinoian loess, on the American side, the Rixdorf of north Germany, unnamed beds in central Russia, and the Mindel-Riss interglacial deposits of the Alps, on the European side.

As representatives of the third glacial stage, the Illinoian of the Labrador field and doubtfully the "so-called Iowan of the Keewatin field (Illinoian?)" are put into correlation with the Middle Drift of the north German lowland and the Riss drift of the Alps.

The third interglacial stage brings into comparison the Sangamon soil of the Labradorean field (no equivalent in kind in the Keewatin field) with the Riss-Würm interglacial deposits of the Alps. The main loess deposits of both the American and the European fields are discussed in this connection and made largely interglacial and eolian.

Only four glacial stages are recognized and the comparison ends with the fourth group, which embraces the Wisconsin series of America, the Upper Diluvium of north Germany, the Young Drift of England, and the Würm beds, with the associated Niederterrassen of the Alpine region. The glaciation of the Riesengebirge and the Schwarzwald are also touched on in this connection.

In the summary, some qualifications of the correlations are introduced, the most notable of which is the statement that "the European deposits seem to contain nothing that correlates clearly with the Illinoian drift." The middle drift of north Germany and the Riss, "though standing as representatives of the third glacial stage in their respective regions, each seems to be younger than the Illinoian drift."

It is in the grouping of this third stage and in the treatment of the Iowan that there is likely to be awakened the strongest dissent from the comparison of Mr. Leverett if it be considered—as it is liable to be considered—a representative rather than an individual correlation. It is important, the rather, to note that in the author's own point of view, the third stage, the Middle Drift, presents the most notable anomalies. There is little doubt

that most American glacialists will agree, each in his own way, that the interpretations of the middle drift of America, if we may use the term rather broadly, are those that most invite question and perhaps further readjustment. And so a few of the salient features of the shifting history of American opinion on the middle drift may be pertinent to this review. By American middle drift let us understand the formations that lie between the Aftonian interglacial beds that cap the lowest till and the base of the declared glacial sheets of Wisconsin age.

In an early comparison of American and European glacial formations put in print sixteen years ago in the revised edition of Geikie's *Great Ice Age* (1894, p. 774), the American deposits were given a threefold grouping, with a basal member, the Kansan, a middle member, the Iowan, and an upper member, the Wisconsin, using here the simplified forms the terms subsequently took. The first, the Kansan, was made to embrace the till below the "Forest Beds" and the "Noah's Barn-Yards" that were then supposed to form a common interglacial horizon; the second, the Iowan, was made to include the till above the "Forest Beds" and below the young moraine-ridged sheet which was made to constitute the third or upper division, the Wisconsin. This last division has held its place and name with firmness throughout and shows no signs of instability, but the two earlier divisions have suffered a serious shifting of names and of interpretations, and the end is perhaps not yet at hand. The name Kansan has been shifted from the sub-Aftonian till to the super-Aftonian till originally called Iowan. The term Iowan thus displaced has been transferred from the middle drift to the uppermost and least member of the grouped beds originally covered by the term. The reasons for these shifts seemed cogent to the workers in the Iowan field at the time they were made and perhaps seem so still. They were accepted with slight reluctance by the glacialist who had given the terms their original applications. The cogency of the reasons for the changes has, however, from his point of view, largely disappeared with the progress of study, and if it were practicable to return essentially to the original usage, making the sub-Aftonian till Kansan and the super-Aftonian till Iowan, and to take the exceptional exposures of both formations near Afton Junction, Iowa, as the types, as was originally done, it would seem to him to accord best with the inherent fitness of the case. Particularly does this seem so in the application of the term Iowan, for the super-Aftonian till not only has a broader and more distinctive expression in Iowa that anywhere else, but it is the greatest of Iowa's drifts; it is inherently the Iowan drift. When the shift of terms was made, it was supposed that the uppermost till sheet in eastern Iowa with

its peculiar youthful typography, accidented by remarkable granite bowlders, set superficially, embraced all the upper drift down to the "Forest Bed," in other words all of "the Upper Till" of McGee's classical paper on the drift of northeastern Iowa. As this upper till of McGee was the type of the East Iowan (Geikie's *Great Ice Age*, 760–62), the name naturally followed the new interpretation. The youthfulness of the surface and the freshness of the bowlders of this uppermost formation seemed to force its separation from the well-eroded deeply-weathered sheet which overlies the Aftonian beds at their typical locality. It has since been found, however, that the fresher features of the Iowan belong only to a thin superficial formation, and it will probably now be agreed by most experienced workers familiar with the region that the main part of McGee's upper till is to be correlated with the super-Aftonian till at the typical locality, thus restoring, in large measure, the original applicability of the term.

This sketch, even in its incompleteness, may serve to give a measure of historic insight into the embarrassments that attend the correlation and nomenclature of the American middle drift.

Respecting the newer divergencies of opinion implied in Mr. Leverett's paper, which involve the suggested dismissal of the Iowan altogether, as a distinct formation, or else its grouping under the Illinoian, it is appropriate here to urge restraint, patience, and equipoise, for the distinguishing phenomena, while pronounced and peculiar, are subtle in their gradations and singularly puzzling.

T. C. C.

The Middle Devonian of Ohio. By CLINTON R. STAUFFER. Geological Survey of Ohio, 4th Ser., Bulletin No. 10. Pp. viii + 204, 17 plates. Columbus (1909), 1910.

The first chapter of this bulletin is devoted to a "General Discussion of the Middle Devonian," which is considered under three headings. The first part is a "Historical Sketch" in which the literature of the Middle Devonian formations is carefully and fully reviewed. This is followed by a consideration of "The Middle Devonian in Adjoining Territory," in which the greatest amount of space is given to the equivalent formations of Indiana and Michigan, which have also been studied by the author in the field. In the closing part of the chapter is a "General Description of the Middle Devonian" formations, which in Ohio are the Columbus and Delaware limestones and the Olentangy shale. The Middle Devonian

rocks in Ohio outcrop in three districts, the most extensive of which is a belt with an average width of ten to twelve miles extending from the Ohio River across the central part of the state to the islands in Lake Erie, north of Sandusky, although the limestones do not extend south of Pickaway County. The second district, in the vicinity of Bellefontaine, is in the western part of the state; while the third is a somewhat crescent-shaped area in the northwestern part of the state, sweeping around from the Michigan line to that of Indiana.

The second chapter, which is devoted to a "Discussion of Sections and Faunas," contains a large number of sections of the formations under consideration in Ohio with lists of their fossils. The Columbus and Delaware limestones of Central Ohio have been subdivided into thirteen zones which are indicated by letters ranging from A, which represents the basal conglomerate of the Columbus limestone resting on the Monroe limestone, up to M at the top of the Delaware limestone. Each zone is fossiliferous, with the exception of the lowest one, or Zone A, and following the lithologic description of each one is a list of the fossils common to the zone. In regard to correlation with the standard formations of New York, the conclusion is reached that the Columbus limestone represents the Onondaga limestone and the Delaware limestone, and Olentangy formation the Marcellus shale and Hamilton beds of that state.

In chapter iii "The Relationships of the Middle Devonian Faunas of Ohio" are very fully discussed and it is shown that the Columbus fauna is composed of two elements, one of which came from the north and the other from the south. The last chapter is devoted to "Notes on and Description of Species," in which twelve new species and one variety are named and described.

The bulletin is illustrated by seventeen plates, thirteen of which give views of characteristic portions of the formations described. One is a "Hypothetical Map of the Middle Devonian Sea during Columbus Time" and another of the same sea "During Delaware-Olentangy Time." The last two plates are illustrations of fossils showing the new species which were drawn by Miss Edith Hyde.

The bulletin as a whole gives a scholarly account of the Middle Devonian formations of Ohio and contains a larger amount of information concerning them than any other published work. From a geological standpoint it is an interesting and valuable bulletin ranking among the best published by the Geological Survey of Ohio.

C. S. P.

Petrological Abstracts and Reviews

Edited by ALBERT JOHANNSEN

Announcement.—With this number of the *Journal* a beginning is made in the publication of a series of abstracts and reviews of petrographical papers which it is hoped may be continued in each issue in the future. Whether this will be possible or not will depend largely upon the co-operation of petrologists. With the increasing number of petrographical descriptions, reading and reviewing all articles has become a work too great for one man to accomplish in his spare time, and it is necessary to ask the assistance of all petrographers who are interested in keeping these abstracts up to date. This work was begun too late to cover all the recent literature, but great interest has been shown by the few petrographers who have been consulted, and much aid has been promised for future numbers. It is hoped that authors will themselves send in short summaries of their papers, promptly upon publication, giving reference to publication, volume, etc., as in the abstracts here published. It is especially desirable that new analyses, new methods of determination, and new instruments, be fully described. Summaries and separates for abstracts may be sent to Albert Johannsen, Walker Museum, The University of Chicago.

Barbier, Ph. "Sur un caractère chimique différentiel des orthoses et des microclines," *Comptes Rendus de l'Académie des Sciences*, 1908, CXLVI, 1330.

Spectroscopic analysis of the chlorides of the bases extracted from twenty-five orthoclases and twenty microclines shows that the orthoclases invariably contain small quantities of either lithium or rubidium, or both together, while the microclines contain neither. The author concludes that orthoclase constitutes a definite species characterized by monoclinic form and the presence of small quantities of lithium and rubidium, and that it therefore can be distinguished chemically from microcline.

F. C. Calkins

DUPARC, LOUIS. "Recherches Géologiques et Pétrographiques sur l'Oural du Nord," Pt. III: Le bassin de la Haute-Wichéra, *Mémoires de la Société de Physique et d'Histoire Naturelle de Genève*, 1909, XXXVI, fasc. 1.

Pp. 53–114 are devoted to the petrography of diabases and pre-Devonian metamorphic rocks.

The diabases are of ordinary types, essentially composed of plagioclase and augite. The optical properties of the pyroxene and its alterations are fully described.

The metamorphic rocks comprise quartzites, amphibolites with albite and epidote, albite-chlorite schists, glaucophanites with albite and epidote, sericitic albite gneiss, quartz-sericite schist, and quartzitic schist. Numerous rock analyses are given and the amphibolites are said to be derived from diabases. The optical properties of the amphiboles are described with much detail. Amphiboles related to glaucophane occur in many of the schistose rocks.

F. C. CALKINS

FINLAYSON, A. M. "Petrology and Structure of the Pyritic Field of Huelva, Spain," *Geol. Mag.*, 1109, VII, 220–29. Figs. 3, pl. I.

The pre-Cambrian rocks which occur in this area consist of gneisses, hornblende schists, crystalline and metamorphic limestones, succeeded by less altered schists and phyllites. Cambrian schists with quartzites and greywackes are conformable with the upper members of the crystalline series. Granites of varying composition occur as a series of intrusive bosses. Rhyolite, trachyte, syenite, and monzonite porphyries occur and are thought to be intrusive in agreement with Vogt and opposed to Klockman. Basic intrusions, consisting of diabases, augite porphyrites, dolerites, and augite diorites are mentioned.

ALBERT D. BROKAW

GOLFIER, J. "Recherche des paramètres qui caractérisent les types classiques de roches éruptives," *Bull. Soc. Geol. Fr.*, 4th ser., 1908, VIII, 55–64.

The author attempts to define chemically the divisions of the current classification developed by Rosenbusch and others.

The "parameters" used for the purpose are certain especially character-

istic ratios derived as follows: Let the atomic proportions of Si, K, Na, Ca, Mg, Fe, be represented by s, k, n, c, m, f. Then

$$A=\frac{k+n}{k+n+c+m+f}\times 100, \quad Sa=\frac{s}{k+n}$$

$$MF=\frac{m+f}{k+n+c+m+f}\times 100, \quad Ss=\frac{s}{k+n+c+m+f}$$

It is found that in the second edition of Rosenbusch's *Gesteinslehre* the names of analyzed rocks, with relatively few exceptions, are used in accordance with the following scheme:

	Sa>5.5	Sa<5.5 >4.15	Sa<4.15>2.9	Sa<2.9
A>50 Alkaline magmas	Granites		Alkali syenites	Eleolite syenites
A<50>25	Diorites	Normal syenites	Theralites	
A<25 MF<75 Mixed magmas	Ss>1.1, Gabbro		Ss<1.1 Shonkinites	
A<25 MF>75 Ferromagnesian magmas	Peridotites			

Rosenbusch's syenites are divided into "normal" and "alkali" syenites, while his essexite, theralite, and shonkinite and ijolite-missourite families fall in the "theralites" and "shonkinites" of the table.

F. C. CALKINS

HILLEBRAND. W. F. "The Analysis of Silicate and Carbonate Rocks," *Bull. U.S. Geol. Survey No. 422*, 1910. Pp. 239. Figs. 27.

A revision of *Bulletin 305*. The following are the more important changes and additions. The effect of fine grinding upon the ferrous iron content is discussed in the chapter on the preparation of the sample, and again in the chapter on the determination of ferrous iron. To minimize the error due to oxidation the sample may be ground in absolute alcohol. This apparently does not reduce ferric minerals.

The chapter on water has been rearranged and is introduced by a section on the rôle of hydrogen in minerals, in which a provisional classifica-

tion of the condition of hydrogen in minerals is developed. The author advocates the weighing of the air-dry powder and determination of moisture rather than the weighing of the perfectly dried sample, as the latter takes up water on the unavoidable exposure to the air during weighing, etc.

A considerable addition is made to the chapter on the determination of titanium, with the view to minimizing the error due to the bleaching effect of alkali salts on the color produced by hydrogen peroxide.

A new indirect method for determining fluorine, devised by Steiger and modified by Merwin, is introduced. This method is based on the fact that fluorine has a powerful bleaching effect on the yellow color resulting from the oxidation of a titanium solution by means of hydrogen peroxide. Steiger's and Merwin's diagrams are introduced.

A number of alterations of minor importance have also been made.

ALBERT D. BROKAW

JOHANNSEN, ALBERT. "Some Simple Improvements for a Petrographical Microscope," *Am. Jour. Sci.*, 4th ser., 1910, XXIX, 435–38. Figs. 4.

The writer describes (1) a rotating upper nicol in which the annoying reflection of light from the surface is overcome; (2) a permanently attached combination wedge, combining a gypsum plate and a combination quartz-mica wedge in a metal casing. An indicator shows the order of the interference color appearing in the field; (3) a rotating lower nicol for observing very slight changes of pleochroism; (4) improvements to the Hirschwald stage.

ALBERT D. BROKAW

LACROIX, A. "Sur l'existence à la Côte d'Ivoire d'une série pétrographique comparable à celle de la charnockite, *Comptes Rendus de l'Academie des Sciences*, 1910, CL, 18–22.

The rocks described have a vast development in the western part of the Gold Coast territory. They range from hypersthene granite, almost wholly composed of quartz and feldspars, to a norite free from quartz and containing at least 50 per cent of hypersthene.

Four analyses are given. These illustrate the following chemical characteristics; relatively high iron and magnesia, varying inversely as SiO_2, (71.80–54.33); slight variation in soda (3.52–4.35), rapid decrease in potash (4.11–0.59) as silica decreases; relatively small variation in lime

(2.20–5.60) which is almost wholly contained in plagioclase with 21–43 percent An.

The great interest of the rocks lies in the fact that they belong to a rare family supposed by Rosenbusch to be possibly co-ordinate with the alkali and lime-alkali families. These are principally developed in three other regions: India, S. Norway, Canada, and the Adirondacks.

The magmatic relations to the harzburgites, norites, and diabases, partly hypersthene-bearing, of Guinea and Sierra-Leone are still to be determined.

An alkali granite containing a soda amphibole is found farther north surrounded by granites of non-alkaline facies.

Ordinary biotite granites are abundant about the sources of the Niger.

F. C. CALKINS

LOUGHLIN, G. F. "Intrusive Granites and Associated Metamorphic Sediments in Southwestern Rhode Island," *Am. Jour. Sci.*, 4th ser., 1910, XXIX, 447–57. Maps 2.

From his studies in southeastern Connecticut and southwestern Rhode Island, the author became convinced that all of the granites of that area are parts of one batholith, not of pre-Cambrian age, but intrusive into rocks which have been mapped as Carboniferous. In a former paper, not yet published, a detailed report was made of the Connecticut area. The present paper gives the results of a continuation of the work eastward into Rhode Island.

In the Connecticut area the granites, which the writer calls the Sterling granite series, include normal biotite granite, porphyritic biotite granite, and alaskite; the latter cutting the other two varieties. All are intrusive into the sedimentary series. In the Rhode Island area the same rocks are found, supplemented by a later intrusion, represented by the granite found at Westerly, R.I. Both the sediments and the Sterling granite are cut by dikes of the Westerly granite, which differs from the Sterling granite only in containing a higher percentage of plagioclase.

The author concludes: (1) The Westerly granite is closely related to the Sterling granite and is considered its latest exposed phase. (2) The Sterling granite batholith is continuous from eastern Connecticut to Narragansett Bay, R.I., and includes granite formerly thought to be pre-Cambrian. There are no pre-Cambrian rocks in Rhode Island south of the Washington-Kent county line. (3) The Sterling granite is intrusive into all the sediments with which it is in contact, and its intrusion accompanied metamorphism

and folding. (4) The time of the intrusion is correlated with that of the Appalachian Revolution. (5) The Kingstown sediments were derived principally from felsite porphyry, micrographic granite, and possibly more basic igneous rocks.

ALBERT JOHANNSEN

NOBLE, L. F. "Contributions to the Geology of the Grand Canyon, Arizona. The Geology of the Shinumo Area, Pt. I," *Am. Jour. Sci.*, 4th ser., 1910, XXIX, 369–86.

Describes the Archean rocks (Vishnu) of the area as consisting of a complex of quartz, mica, and hornblende schists, invaded by a batholithic mass of quartz diorite and injected by veins of pegmatite and aplite. These veins are of two ages, the older being folded with the schists, while the younger cut both the schists and the quartz diorite. No attempt is made to work out the general structure of the complex on account of the limited exposures.

ALBERT D. BROKAW

PRIOR, G. T. "On an Analcite Basalt from Rathjordan, Co., Limerick," *Min. Mag.*, 1910, XV, 315–17. Figs. 2.

The rock from Rathjordan has been described by Hull and Alport. According to the latter it is a fine-grained, black basalt which consists of a groundmass of innumerable small grains of augite, magnetite, and amorphous glass, in which are pseudomorphs of altered olivine and feldspar. The present writer adds that in the supposed glassy groundmass there are also thin needles, probably apatite, and some isotropic material which, under the microscope, resembles leucite.

A small portion of this isotropic material was isolated and subjected to microscopical and chemical tests. There were strong reactions for sodium while none were obtained for potassium. He concludes, therefore, that most of the supposed leucite is probably analcite. In order to check this conclusion an analysis of the rock was made which appears as follows: SiO_2, 40.81; TiO_2, 3.86; Al_2O_3, 13.08; Fe_2O_3, 6.40; FeO, 7.20; MnO, 0.07; CaO, 10.12; MgO, 10.03; Na_2O, 2.43; K_2O, 0.31; P_2O_5, 0.88; H_2O at 110°C., 0.82; H_2O above 110°C., 3.97. The small amount of potash shown by this analysis seems to confirm the above conclusion. The rock is therefore an analcite-basalt. This analysis is compared with one of a leucite basalt from Bohemia, and one of an analcite basalt from Colorado. In the case of the latter rock, Cross argues, that judging from

the freshness of the other constituents present, the analcite is probably primary. However no such an argument applies to the analcite of the Rathjordan basalt as the rock is much altered. The author suggests that possibly this rock was originally a leucite basalt and that the leucites have been subsequently altered to analcite.

CLARENCE W. RUSSELL

RANSOME, F. L., EMMONS, W. H., and GARREY, G. H. "Geology and Ore Deposits of the Bullfrog District, Nevada," *Bull. U.S. Geol. Survey, No. 407*, 1910. Pp. 130. Figs. 20, Pl. 13.

Two areas of pre-Tertiary crystalline rocks are described. The first consists of quartzite, quartz-biotite and quartz schist, grading through calcite schist into nearly pure marble. A few pegmatite veins and a larger number of quartz veins cut the schists. The schists are overlain by limestone presumed to be Silurian.

In the second area the crystalline complex consists chiefly of quartz-biotite injection schist, pegmatite, and augen gneiss. A "sheared diorite" is thought to be a dike which cut the sedimentaries previous to their metamorphism. A quartz diorite dike cuts the schists and pegmatite and with them is cut by a subsequent diorite dike.

The Tertiary volcanic rocks are described as consisting of sixteen rhyolite flows, five basalt flows, one flow of quartz latite and one of quartz basalt, two sedimentary tuffs, an intrusive rhyolite porphyry, dikes of plagioclase basalt and an intrusive leucite basanite. This rock falls into a subrang of the quantitative classification which has not been previously represented by an analysis from the United States. Five analyses of Tertiary igneous rocks of the region are included in the report.

The Introduction and the Economic Geology section are by Ransome; the General Geology section by Emmons and Garrey.

ALBERT D. BROKAW

TRAVIS, C. "On the Behavior of Crystals in Light Parallel to an Optic Axis," *Am. Jour. Sci.*, 4th ser., 1910, XXIX, 427–34. Figs. 2.

A mathematical explanation of the fact that a section of a biaxial crystal cut normal to an optic axis appears uniformly illuminated in parallel light between crossed nicols. The author concludes: (1) Interior conical refraction, in a strict sense, plays no part whatever as a cause of the phenomenon; (2) The cause is to be found in the fact that so-called parallel

light has commonly a considerable divergence; (3) In any given case, the observed intensity of illumination is equal to the average intensity of that portion of the interference figure bounded by the limits of the pencil of light used.

ALBERT JOHANNSEN

WRIGHT, FRED EUGENE. "A New Ocular for Use with the Petrographic Microscope," *Am. Jour. Sci.*, 4th ser., 1910, XXIX, 415–26. Figs. 10.

A description of an ocular with which the birefringence, the optic axial angle, when one or both optic axes appear within the field of vision, and the extinction angle of a mineral in thin section may be measured.

ALBERT JOHANNSEN

WRIGHT, FRED EUGENE. "A new Petrographic Microscope," *Am. Jour. Sci.*, 4th ser., 1910, XXIX, 407–14. Figs. 4.

The author describes a new petrographic microscope, designed and constructed in the workshop of the Geophysical Laboratory at Washington, and specially adapted to the investigation of the optical properties of minute grains of artificial preparations. The principal differences between this and the usual petrographic microscopes are: (1) Both nicols revolve simultaneously, the connection between the two being a rigid bar; (2) The upper nicol always remains in the tube and the substage nicol is inserted or withdrawn on passing from ordinary light to crossed nicols; (3) The sensitive plate is inserted just below the condenser; (4) It has a simple mechanical stage; (5) The Bertrand lens is mounted in a sliding collar which permits of different magnifications of the interference figure; (6) An iris diaphragm immediately below the ocular is intended for use when observing interference figures directly by the Lasaulx method without the ocular and Bertrand lens; (7) An Abbe condenser is used, and with it a large nicol prism, or an Ahrens prism, 15 mm. edge, after the manner of the Fuess microscope No. I*a*. With this arrangement the entire condenser lens system remains in position and its upper lens need not be removed when low-power objectives are used.

ALBERT JOHANNSEN

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